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AIRCRAFT HANDBOOK

BY

FRED H. COLVIN

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FIFTH EDITION
SEVENTH IMPRESSION

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AIRCRAFT HANDBOOK

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PREFACE

The many changes that have taken place and the advances in aircraft construction made it necessary to rewrite completely the contents of this, the fifth, edition of the *Aircraft Handbook*. The first edition was written in 1917 to aid in the maintenance of the planes then used by our Army and Navy. This fifth edition was prepared before we became involved in the present war, but will, we hope, be even more useful in helping to "Keep 'em flying."

The many changes in engines, propellers, landing gear, and all other details of the modern airplane have made it seem advisable to confine the contents of this volume largely to the maintenance of the power plant and such other details as come within this range. Other books treat of the theory of flight and of the design and construction of planes, but this volume has been prepared to assist the ground mechanic in keeping in the best condition the parts that come under his care. The contents apply equally to fighting craft and to transport planes.

The publication of much of the information here has been made possible by the hearty cooperation of men in the various organizations mentioned throughout the text, largely because of friendships that reach back into the early days of aeronautics. Without them it would have been impossible to obtain much of the valuable data which is reproduced here, and to them goes the great appreciation of the author.

FRED H. COLVIN.

New York, N.Y.,
January, 1942.

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AIRCRAFT HANDBOOK

INTRODUCTION

PLANES AND ENGINES IN GENERAL

The building and maintenance of the modern airplane require a knowledge of many things. The most vital need is absolute reliability on the part of designers, the mechanics, the maintenance men or ground crew, and the pilot. Aside from the needed skill is the need for dependability in all that pertains to the plane. Any mistake or doubt as to the quality of the material or of the workmanship should be immediately reported to those in charge of the work. For the airplane is a machine for which nothing but the best is good enough.

Every aircraft mechanic should always bear in mind that a defective part, an error in fitting, or the least carelessness in assembling a plane, the engine, or any part of one, may help to cause failure in the air. The life of the pilot, the crew, the passengers, the pay load, the plane, and even the solvency of the company itself, may be jeopardized by an oversight, by carelessness, or by an attempt to cover up the mistakes of others. The marvelous reputation for safety in air transport has been made possible only by the care used in servicing and overhauling planes, engines, and all air transport equipment. The importance of the utmost care in all work connected with military aircraft cannot be overestimated.

The more the aircraft mechanic learns about planes and their equipment, the more valuable he becomes to himself and to his employer. Complete familiarity with them and their equipment is growing increasingly difficult with the coming of new engines and new devices of various kinds. The use of such materials as aluminum, duralumin, magnesium, the many kinds of steels, and the ever growing number of plastics, is now an important part of airplane work. Methods of handling these materials so as to secure the best results is a study in itself. Welding has proved a great boon in the building of the fuselage and wing structures, when made of steel tubing; but it must be employed most intelligently in the handling of aluminum and its alloys on account of its effect on the strength of these materials.

Familiarity with the internal-combustion engines used in automobile work is of great service to any airplane mechanic. But the differences in the duty demanded of those types of engine and that demanded of airplane engines must be given due consideration. The main difference is that the amount of power demanded regularly of airplane engine is far greater than that of the engine in our car. For, although it is not good practice to run even the airplane engine at its power peak except in take-off, it does run at a much higher power than its counterpart on the ground. The automobile seldom runs at more than 25 per cent of its maximum power, except on rare occasions.

Ignition, spark plugs, and carburetors are all under a greater strain, owing partly to the higher power and partly to the frequent and sudden

changes in running conditions, such as altitude and temperature. In addition are the many accessories now in use such as starters, propellers with variable pitch, both manually and automatically controlled, retractable landing gears, instruments of many kinds, brakes, and many other devices. All of these must be inspected; most of them must be lubricated at regular intervals; and they must be disassembled and repaired when necessary.

Types of Engines.—There is, at present, only one liquid-cooled aircraft engine in production in this country. This is the Allison engine being built for military use. The liquid-cooled engine has the advantage of being built with the cylinders in line, presenting less frontal area. It has however the great disadvantage of a long crankshaft which cannot avoid all torsional distortion, even when made very heavy. The Allison is normally made in a V-12 design. There are also designs for a double V-12, with two crankshafts geared together to a central propeller shaft. This naturally has a much greater frontal area than the single V engine. The radial engine presents a large frontal area but has a very short crankshaft.

A late design by the Pratt and Whitney Division of United Aircraft gives a 2,000 hp. radial, air-cooled engine, with about the same frontal area as the Allison liquid-cooled engine. This development may affect the future design of planes as well as of engines.

Other types of engine have also been made. The so-called "pancake" engine, which has a series of opposed cylinders, has been tried but is not in use to any extent. It is similar to the opposed-cylinder Continental, Franklin, and Lycoming engines, but has more cylinders in line.

Barrel-type engines have also been designed and tried over a long period. They date back to the steam days and include such names as Colt, Arnold, Torbert, and others. The Army Air Corps did a lot of experimental work on this kind of engine at Wright Field, Dayton. The only engine of this type now in active development is that of Karl Herrman. It presents a very interesting engineering problem, which may be solved to the great advantage of all users of internal-combustion engines.

Diesel engine development has also received much attention from many sources. One of the most successful of these was the Packard, but with the death of Woolson, its designer, the efforts to commercialize it ceased. Other designers have been, and are, working on the same problem. The only diesel engine now actually being used in aircraft is the Guiberson of Fort Worth, Tex. It is, as yet, more or less experimental but may prove to be thoroughly practical.

It has seemed best to put the airplane engines in three general groups: the high-power engines, the medium-power engines, and the small engines. This supplies a more logical classification than one by type, which would separate the line engines from the opposed-cylinder types, and the Allison liquid-cooled from all the rest.

In each case the maker's suggestions as to care and maintenance have been followed. Many of the given operations require special tools which are supplied by or can be obtained from the maker, although as a rule they are not shown or designated in order to avoid confusion. Unless the operations can be performed satisfactorily with standard tools and wrenches, the specials should always be used to prevent the possibility of damage.

The larger engines will be shown first.

SECTION I

ALLISON ENGINES

The Allison engine is the only liquid-cooled aircraft engine made and used in the United States. The illustration shows a 12-cylinder 60-deg. V engine, known as V-1710-C15 model, the 1710 representing the capacity of the cylinders in cubic inches. A single-stage supercharger is built into the engine. The liquid used is ethylene glycol which permits a cylinder temperature of 260°F., securing more power and greater efficiency than is possible with water, which boils at 212°F. at sea level and much less at high altitudes.

Designs have been made for a double-V engine, each with independent crankshaft and both gearing to the propeller shaft. This makes it possible to have a gun through the propeller shaft. The single V is rated nominally at 1,000 hp.; actual ratings are 960 hp. at 2,600 r.p.m. and at 12,000 ft.; 1,090 hp. at 3,000 r.p.m. at 13,200 ft. The take-off power is 1,040 hp. at 3,000 r.p.m. at sea level.

The principal dimensions of the engine are as follows:

Specifications of Allison V-1710-C15 Engine

Bore, in.	5.50
Stroke, in.	6.00
Piston displacement, cu. in.	1,710
Compression ratio	6.65 to 1
Blower gear ratio	8.77 to 1
Impeller diameter, in.	$9\frac{1}{2}$
Propeller reduction rear ratio	2 to 1
Average weight of engine, lb	1,325
Over-all dimensions of complete engine:	
Length, in.	$97\frac{17}{32}$
Width, in.	$29\frac{9}{32}$
Height (max.), in.	$41\frac{3}{16}$
Number of mounting bolts	8
Transverse spacing of mounting bolts, in.	$18\frac{3}{8}$

Ignition

Magneto, Scintilla double fixed timing, type	DF
Direction of rotation viewing mounting pad	R.H.
Magneto speed, ratio to crankshaft speed	1.5 to 1
Spark-plug model	BG-LS 321
Spark-plug gap, in.	0.015
Spark advance, deg. B.T.C.:	
Intake side	29
Exhaust side	35

Valve Timing Data

Intake opens, deg. B.T.C.	52
Intake closes, deg. A.B.C.	66
Exhaust opens, deg B.B.C.	76
Exhaust closes, deg. A.T.C.	26
Intake remains open, crankshaft deg.	298
Exhaust remains open, crankshaft deg.	282
Valve lift, in.	0.533
Valve rocker clearances (cold), measured at valve stem tip for timing and running:	
Intake, in.	0.010
Exhaust, in.	0.020

Fuel System

Fuel consumption at altitude (approx.):	
Full throttle, auto rich, 2,600 r.p.m., gal. per hr.	101
Max. cruising, auto rich, 2,280 r.p.m., gal. per hr.	62
Fuel required—A.E.C. spec. no.	123
Fuel pressure, lb. per sq. in.	10–14

Lubrication System

Oil consumption, qt. per hr. (approx.):	
Full throttle, 2,600 r.p.m.—max.	13.5
Full throttle, 2,600 r.p.m.—normal	8.1
Max. cruising, 2,280 r.p.m.—max.	9.5
Max. cruising, 2,280 r.p.m.—normal	5.6
Oil required:	
Summer grade, A.E.C. spec. no.	124
Winter grade, A.E.C. spec. no.	127
Minimum safe quantity of oil in *engine* system, gal.	3
(Add to this quantity for oil-cooling system and tank)	
Speed of oil pump, times crankshaft speed	1.25

Accessories and Weights in Pounds

Carburetor	43.0*
Exhaust flanges, with gaskets and nuts	9.0*
Export shipping box	900
Generator drive (wt. added)	None
Gun synchronizer, each	2.7
Oil strainer (Cuno)	4.1*
Priming connections and lines	1.5*
Propeller hub (no. of blades)	None
Radio shielding complete	31.1*
Tool kit	

* These items are included in the average engine weight of 1,325 lb.

Note: B.T.C. = before top center; A.B.C. = after bottom center; B.B.C. = before bottom center; A.T.C. = after top center.

Two general views of the Allison engine are shown in Figs. 1 and 2, the first showing a left front view, the second showing the other side and the location of the accessories. Taken in connection with the skeleton view (Fig. 3), they show how the gun synchronizer and other connections are driven.

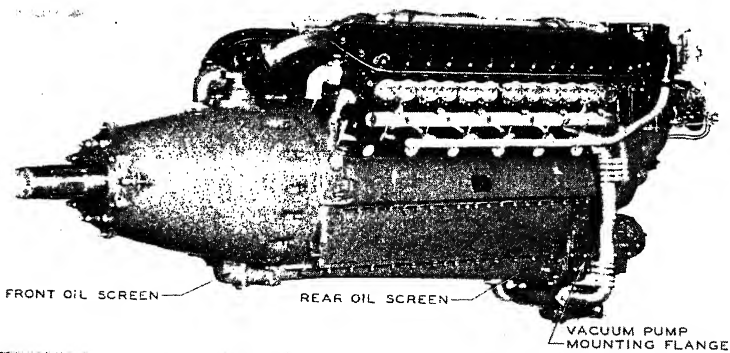


FIG. 1.—Left front view of Allison V-1710 engine.

CONSTRUCTION

Each set of six cylinders has a cast aluminum head, six hardened steel cylinder barrels, and a cast aluminum jacket. The cylinder barrels are a shrink fit in the head, the water jacket bolts against the head and fits

around the barrel, a flange on the barrel clamping it to the crankcase when bolted in place. The coolant is in direct contact with the outside of the cylinder barrel. The jacket is corrugated slightly to allow for expansion.

Each set of cylinders constitutes a cylinder block unit that is held to the upper crankcase by 14 stud bolts that extend through the head. These studs transmit the power stroke forces directly to the crankcase so that the shrink-fit joints take none of the operating loads. There are two intake and two exhaust valves for each cylinder. The intake valves are of tungsten steel and have hollow stems. The seats are of aluminum bronze. The exhaust valves are faced with Stellite and are sodium cooled. The exhaust valve seats are of forged steel and are also faced with Stellite.

There are six rocker arm assemblies operated by a single camshaft on top of each cylinder bank, each camshaft being driven by bevel gears

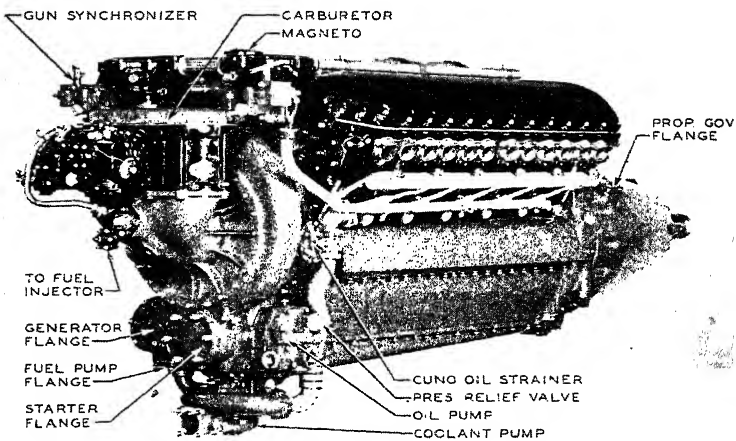


FIG. 2.—Right side of Allison V-1710 engine, showing location of accessories.

through a separate inclined shaft, from a vertical shaft in the accessory housing. Seven equally spaced bolts hold the bevel gear to the camshaft and the gear has 36 teeth. This combination provides a minimum timing increment of 2.8 deg. of crankshaft rotation.

The crankshaft is a six-throw, seven-bearing type with the counterweights welded to the crankshaft forging. A dynamic vibration damper of the pendulum type and a spur gear to drive accessories are splined to the accessory end of the shaft. The reduction gear pinion is splined to the propeller end of the shaft, a roller bearing being used between the reduction pinion and crank throw 6. All journals are hollow with removable aluminum plugs to prevent oil escape at the ends.

The connecting rods are of the forked and blade type, sometimes known as the "spade" type. They are of forgings and machined all over. The bearings are flanged steel shells lined with copper lead bronze, clamped in the forked rod by two bearing caps. (See Fig. 20 for details.) The pistons are

aluminum alloy forgings with three compression rings above the piston pin and two oil control rings, in the same groove, below the pin. The pin floats in rod and piston and is held by a snap ring at each end.

The propeller shaft runs at half the engine speed, reduction being secured by a pinion splined to the crankshaft, meshing with a large internal gear bolted to the propeller shaft. Figure 3 shows the gear reductions to all the gear-driven units. There are two hollow shafts. The inner carries the torque from the crankshaft pinion and the outer shaft the propeller. The connection at the geared end is through a friction plate vibration damper.

The lubrication diagram, Fig. 4, shows clearly how oil reaches every part of the engine.

The centrifugal coolant pump has two outlets that connect by external pipes to the cooling jackets. Each cylinder receives the proper amount of coolant through a metering jet and stainless steel sleeves direct it to the

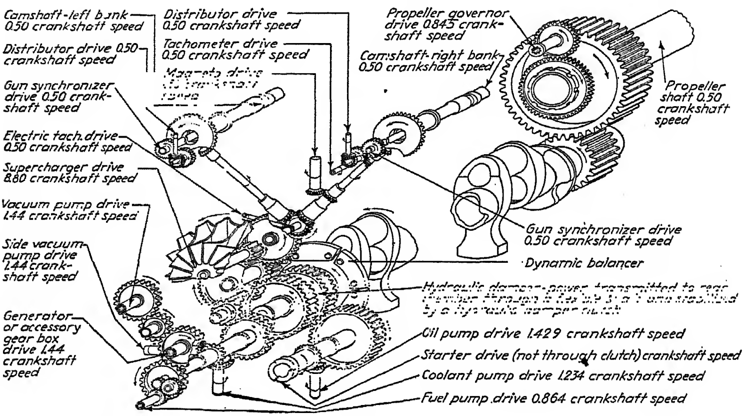


FIG. 3.

hottest part of the cylinder. There is a coolant return at both ends of each cylinder head. On tractor planes, the front outlet is used and the rear outlet closed.

Forced induction is used to deliver the fuel-air mixture to the cylinders. A Bendix-Stromberg three-barrel injection-type carbureter is mounted on the supercharger inlet cover. Fuel is injected directly on the supercharger impeller through a nozzle in the elbow. A branched manifold system distributes the mixture to the cylinders. A backfire screen in the branch manifold of each cylinder block prevents backfire flames from reaching the supercharger.

Dual high-tension Scintilla type DF magnetos are used, the voltage being distributed through two separate distributors driven by the camshaft. The magneto timing is fixed and fires the exhaust plugs 6 deg. before firing the plugs on the intake side.

To understand the relation of the different units, a study of the gear train of the Allison engine as outlined in Fig. 3 is necessary. The crankshaft gear

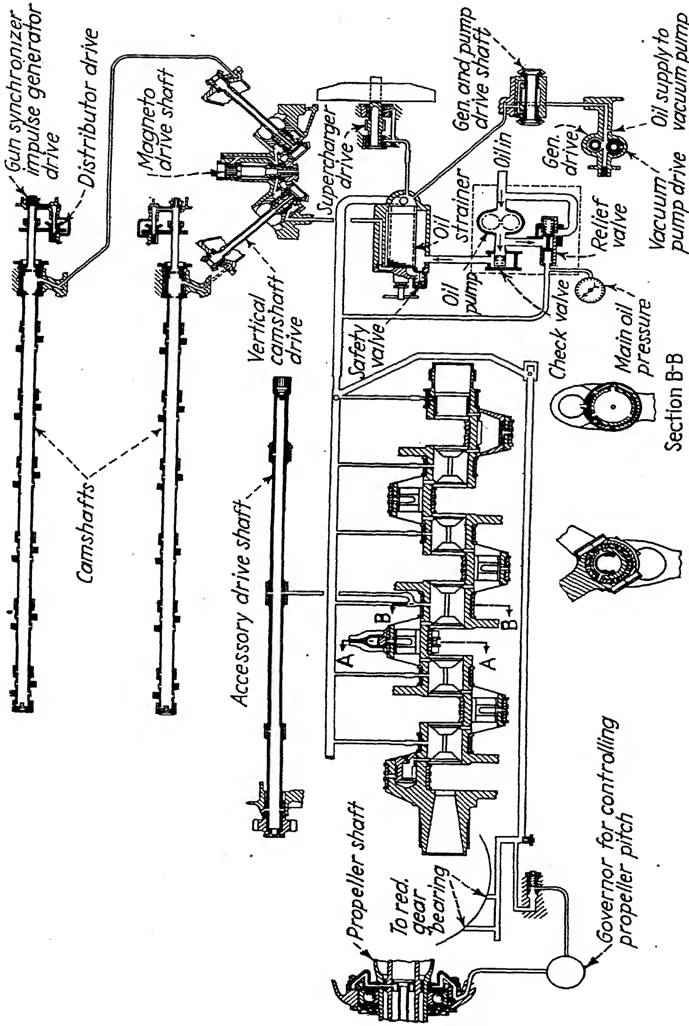


FIG. 4.—Lubrication diagram of the Allison V-1710 engine.

A drives the propeller shaft *B* and in the same direction, by means of the internal gear *C*. The upper side of the internal gear drives the accessories shaft *D*, also in the same direction.

The right-hand (or rear) end of the shaft *D* drives the supercharger impeller *E*, and also the magneto drive shaft *F*, as well as the two camshafts *G* and the two distributors *H*. A projection on the camshaft *I* drives the machine-gun synchronizers to time the guns so that they will shoot between the propeller blades. Tachometer drives are shown at *J*.

The gear *K*, below the end of the crankshaft, drives the vacuum pump, the fuel pump, the generator, the coolant pump, and the oil pump, as shown. The geared extension *L* carries a clutch jaw on the end, by which the starter is connected with the engine, and turns the crankshaft to start it. The relative speeds of these various units are given in Fig. 3 and are of interest.

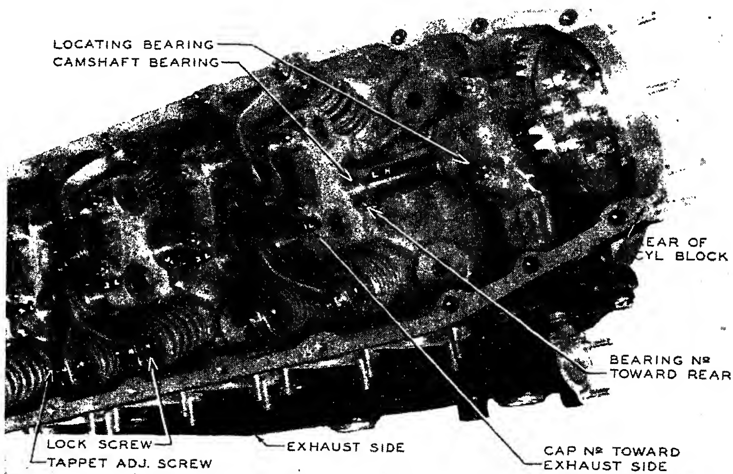


FIG. 5.—Valve operating mechanism.

Details of the valve-operating mechanism are seen in Fig. 5. The central camshaft runs in eight plain bearings, one being larger and flanged, next to the bevel driving gear. Oil under pressure flows through the hollow camshaft. A small hole in the heel of each cam furnishes splash lubrication to the end of the valve stem and the other bearings.

Gun Synchronizers.—Both Figs. 2 and 3 show the location of the magnetos and gun synchronizer. The speed of the synchronizer is half that of the crankshaft. It can be timed in increments of 0.71 deg. without dismounting it from the engine, by removing the cover plate in front of the plunger locking pin and *loosening* the nut on the cam drive shaft. *Do not remove the nut;* merely back it off three or four turns. With the propeller set at the desired position for firing, turn the synchronizer cam to proper position, tighten the nut, and replace the cover. A single-lobe cam is

used with three-bladed propellers; a double-lobe cam for two-bladed propellers.

Distributor Heads.—Both distributor heads are at the rear of the engine. The firing order, as shown by the numbered disks on top of the distributor heads, *is that of the magneto and not of the cylinders.* The firing is as follows:

Contact No.	1	2	3	4	5	6	7	8	9	10	11	12
Ignition cable No.	1L	6R	5L	2R	3L	4R	6L	1R	2L	5R	4L	3R

Do not tighten the three screws too much; just enough to hold the head securely. *If the head has been washed in gasoline be sure that it is perfectly dry before using it.* Gas vapor might be ignited by a spark.

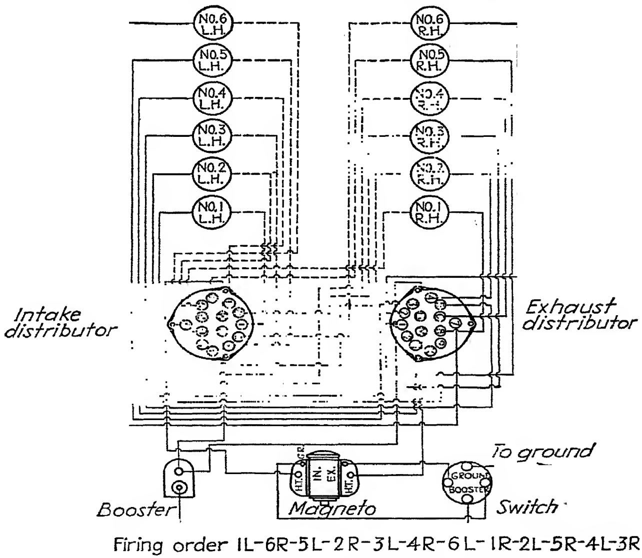


Fig. 6.—Wiring diagram of Allison V-1710 engine.

The wiring diagram is shown in Fig. 6, and the distributor and ignition shielding assembly in Fig. 7.

UNCRATING AND INSTALLING

No special instructions seem necessary to those at all familiar with handling airplane engines. The upper part of the engine shipping box is merely a cover, held by four ½-in. bolts. After removing the hold-down bolts, use a sling as in Fig. 10. Two of the hooks go under No. 7 right- and left-hand hold-down studs. The engine must be hoisted vertically and not allowed to swing; the same sling will handle the engine into the plane. Take care that no part of the accessory section is damaged. The starter and

generator may be installed before being mounted if clearances in the plane are limited.

If the engine has not been run for a week or longer, be sure to fill the injection-type carburetor with gasoline and let it stand at least 4 hr. before starting the engine. This is necessary to condition the diaphragms of the carburetor so that they will function properly.

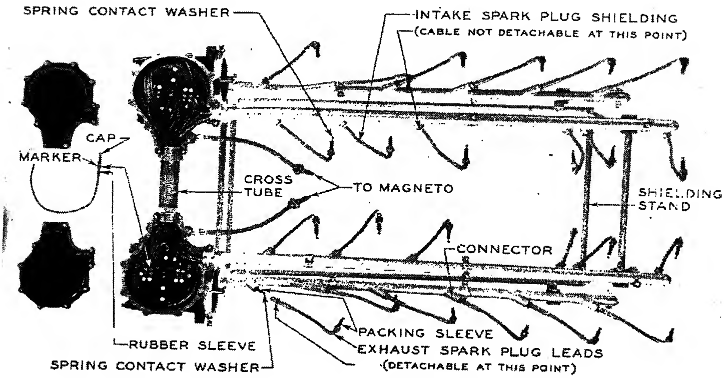


FIG. 7.—Distributor and ignition shielding assembly.

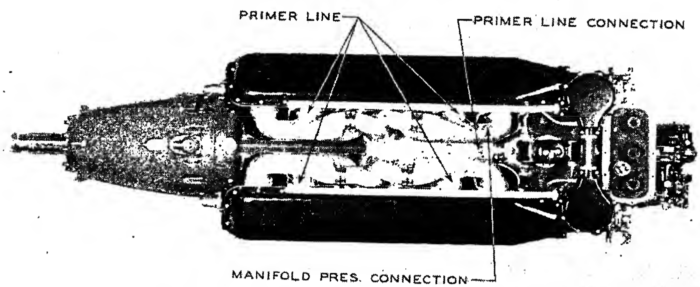


FIG. 8.—This shows the compactness of the intake manifold system.

Overhaul of Engine.—As with all airplane engines, special tools are necessary to reach some of the nuts and other parts. Special fixtures are also provided to hold parts in their proper position. These tools and fixtures are supplied with the engine and must be made available to the mechanic who is to do the work.

To Remove the Shielding Assembly from the Engine

Disconnect the spark-plug terminals. Remove the screws that hold the cable tube brackets to the engine. It is not necessary to remove the brackets

from the tubes. Next loosen the union connecting nuts on all four cable tubes at the distributor housings. Disconnect the magneto wires at the magneto. On each cylinder head, loosen about six of the cylinder-head cover screws nearest the distributor housing. This operation releases the rubber packing gland which is clamped in a groove of the distributor housing diameter by the covers. After removing the four nuts and palnuts from the flange of each distributor housing, the ignition shielding and distributor housings are free to be removed from the engine as a unit.

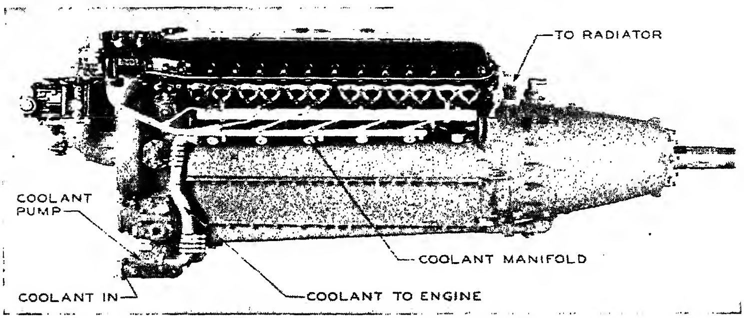


FIG. 9.—Connections for the cooling system.

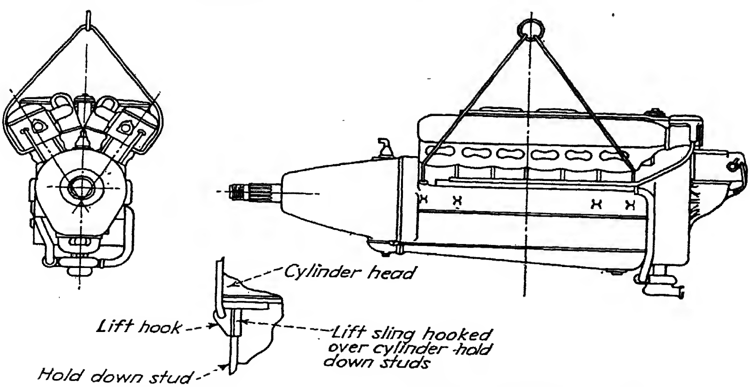


FIG. 10.—Lifting sling for use in handling Allison engine with crane.

Intake Manifold and Cooling System.—The compactness of the Allison design can be noted in Figs. 8 and 9; the first shows the intake manifold system and the second the cooling system. These illustrate the various connections in both systems and will prove of value in understanding the details.

Use an assembling stand which permits rotating the engine so it can be worked on in any position. A ¾-ton hoist should also be available. Although the lifting sling (Fig. 10) is best, a long cable sling can be used.

It should pass under the front part of the crankcase and under the accessory housing. Care must be taken to avoid damage. A careful study of the details shown in the illustrations will make it easier to understand the repair instructions that follow.

Each major subassembly should be removed as a unit after removing the attaching parts. With cylinders of one bank vertical, remove the 14 hold-down nuts and lift the complete block from the crankcase. It should be a straight lift to avoid bending the studs. Watch the pistons as the block lifts off to prevent damage to either pistons or rods by falling against the crankcase.

The piston rings should be kept in groups for each piston, although it is best to renew the rings at each engine overhaul. The retainer rings at the end of the piston pins should also be discarded and new rings used. *Never*

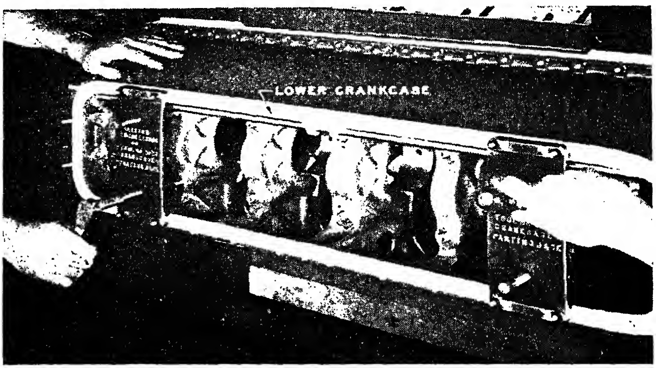


FIG. 11.—Separating the halves of the crankcase with special parting jack.

use old cotter pins or safety wire the second time. If the pins do not push out easily, heat the piston in engine oil to about 140°F.

Crankcase.—The crankcase is made in two parts. Remove the cylinder-block bearing plates from the upper crankcase. Each is held by two flat-headed screws. Turn the engine in a horizontal position, as in Fig. 11, and remove the cotter pins and nuts. The parting jacks shown are bolted to the lower crankcase studs. Be sure the jackscrews are clear of the main bearing. Tightening the jackscrews evenly separates the halves of the crankcase.

Valves.—Valves can be easily removed and replaced by using a spring compresser, as in Fig. 12. This makes it easy to remove the spring retainers from the valve stems. The valves are then taken out through the cylinder. Valves are also replaced by reversing the process.

Coolant Leaks.—Leaks in the cooling system are checked on the stand, as in Fig. 13. Here the cylinder block is bolted down firmly. Connect the coolant heating system until the temperature reaches 250°F., then apply 40 lb. of air pressure. Inspect all points where leaks might possibly occur. Before removing the jacket, if this should be found necessary, measure the cylinder bore and examine it for surface damage. If the bore is more than 0.010 in. out of round, it should be replaced. Note the size to be compared with the replacement cylinder.

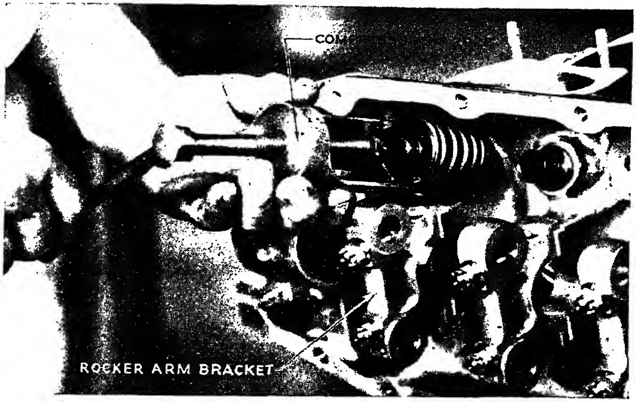


FIG. 12.—Using spring compressor to remove valves.

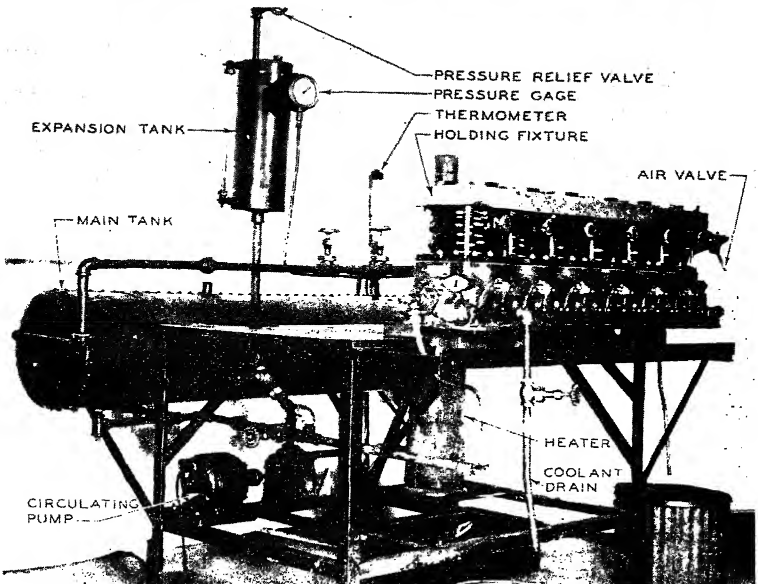


FIG. 13.—Test stand for checking leaks in the cooling system.

A special cylinder-barrel plug and suitable wrenches are provided for the removal of cylinder sleeves. Two 150-lb. men are needed for this job. Details of the coolant seal at the cylinder-barrel nut are seen in Fig. 14. Lift the coolant jacket from the cylinder assembly. The six ring-type steel gaskets will come off with the jacket. Remove the one copper ring-type gasket from each barrel and the long aluminum gasket from the cylinder head.

In removing the coolant jacket, care must be taken to avoid damage to the joint surfaces. These surfaces are covered with varnish, which must be removed by a varnish remover. Any attempt to scrape this surface will damage it and make lapping necessary. Not more than 0.005 in. can be lapped from the surface that fits the crankcase, but as much as 0.015 in. may be lapped from the top surface. This emphasizes the great care that must be taken to avoid damaging this surface.

Metering Plugs.—To secure uniform cooling there are metering plugs for four of the six cylinders in a bank or block. No plugs are used for cylinders 1 and 2. The other four cylinders have the following openings:

Cylinder No.	In.	Cylinder No.	In.
3	$^{27}/_{32}$	5	
4	$^{25}/_{32}$	6	---

Coolant leakage where the cylinder barrel is shrunk into the head, or where the bore is scored or more than 0.010 in. out of round, requires replacement of the barrel. To remove the old barrel, the head is mounted on a planetary cylinder grinder and the barrel cut off by a wheel ⅜ in. wide, close to the head. A 1-in. wheel is then used to grind out the part of the barrel remaining in the head. When ground to a thickness of 0.010 in. the shell is carefully removed with pliers.

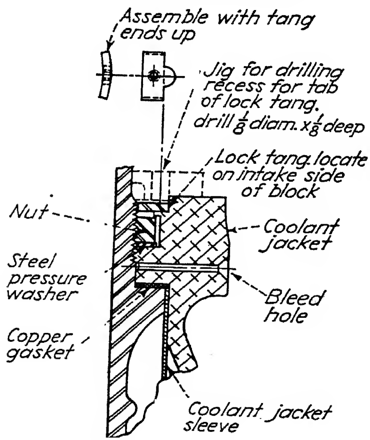


FIG. 14.—Details of the seal used for the coolant joint.

An oven and refrigerator are used in shrinking in the new barrel and also the valve seat inserts. For the barrel, the head is heated to 450°F. while the barrel is being cooled below zero with dry ice. The barrel is then set in place by the guide. This must be done quickly, accurately, and without hesitation, otherwise the parts may seize before they are correctly in place.

Then the barrel flange must be refaced, 0.012- to 0.021-in. material being left for this purpose. The new barrel will also have 0.025-in. stock on the inside for grinding. A carborundum A46-S-100 wheel, 5 × ½ × 1¼ in., is recommended with the wheel cut to ⅜-in. face. After grinding to 5.500 in. + 0.0015 or −0.000, the wheel is used to cut a relief 0.005 in. deep at the cylinder-head end of the wheel. After being ground the barrels are honed with an eight-bladed hone. Taper or out-of-roundness must not exceed 0.001 in. when finished.

The barrel should be kept flushed continuously while grinding to avoid distortion. A mixture of 32 parts water and 1 part International Compound No. 137 is recommended.

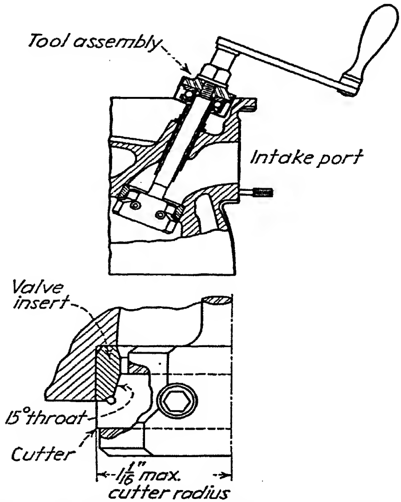


FIG. 15.—Tool for reducing the width of the valve s

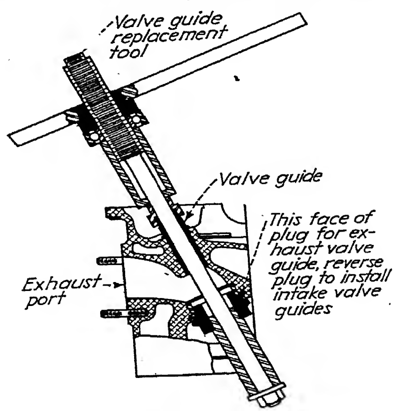


FIG. 16.—Tool for replacing valve guides.

When the width of the valve seat exceeds 7⁄64 in., it must be reduced. Figure 15 shows how this can be done without removing it from the cylinder.

Should a valve guide need replacement the old one can be removed with a fiber drift. A new guide can be put in by using the tool shown in Fig. 16. The ball-bearing nut in the handle forces it into place. Use a light coat of

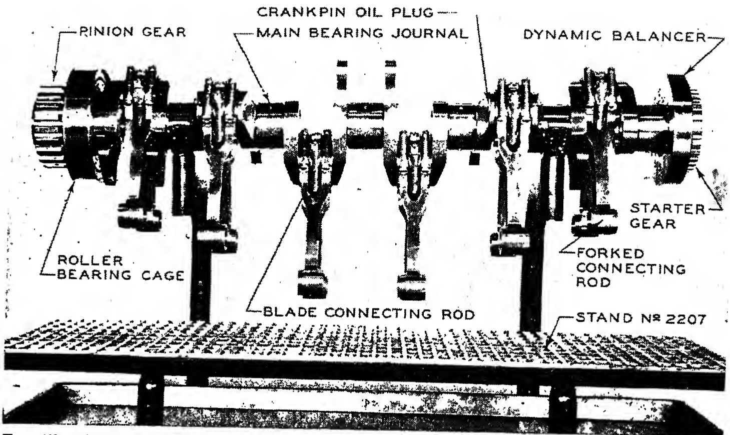


Fig. 17.—A convenient stand for overhauling crankshaft and connecting rod bearings.

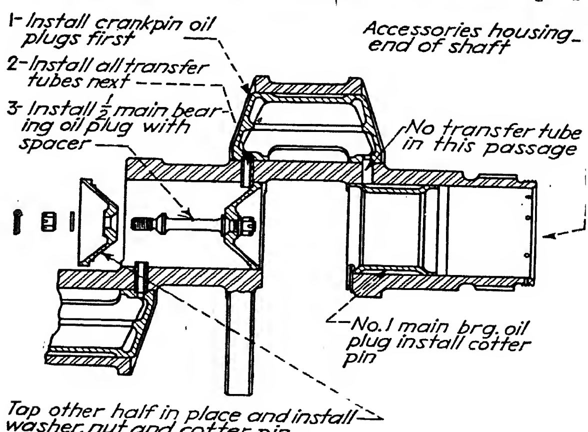


Fig. 18.—Oil plugs and tubes that connect the oil cavities.

petrolatum on the guide before forcing it in. When this begins to squeeze out from under the shoulder of the guide, the tool should be removed.

Never grind a valve in the insert in the cylinder head with a valve-grinding compound.

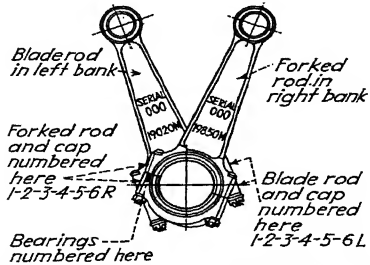


Fig. 19.—Identification numbers on the connecting rods, bearings, and caps.

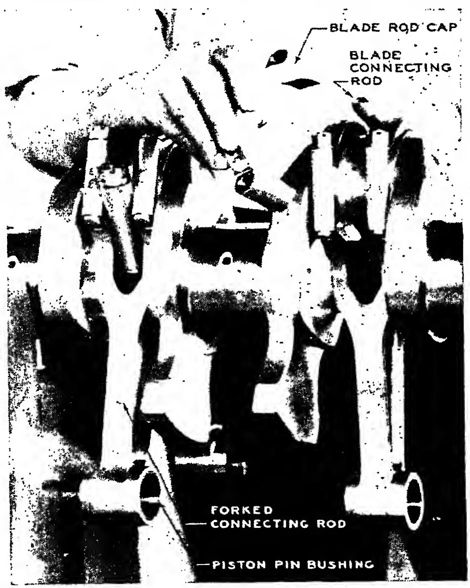


Fig. 20. –Assembling the blade rod and its cap on the spade, or forked rod.

Crankshaft and Connecting Rods.—Such an overhaul stand as is seen in Fig. 17 is most convenient for crankshaft and connecting-rod work. Figures 18 and 19 show details of the rods. The main journal oil plugs are removed first, these being aluminum caps held by studs and nuts. The transfer tubes, shown in Fig. 18, carry oil from the main bearings to the crankpins

and lock the crankpin plugs in place. These transfer tubes (10 in all) must be removed with the fingers, then the pin plugs can be driven out with a fiber drift. Oil plug 6 is pulled out by a rod screwed in a ¼–20 N.C. thread in the plug.

The connecting rods are numbered as seen in Fig. 19; Fig. 20 shows how the blade rod and cap are assembled inside the forked rod.

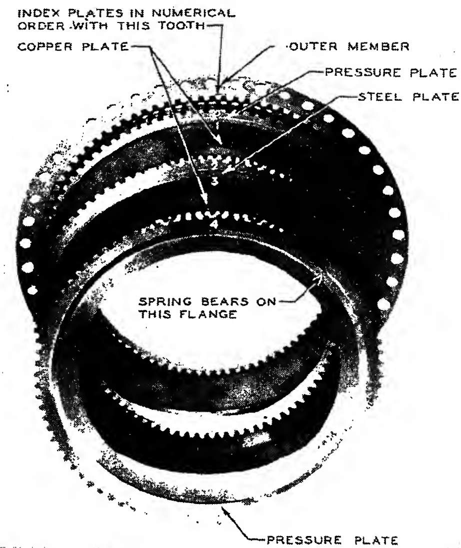


FIG. 21.—Vibration damper plates must be assembled in this order.

The Vibration Damper.—In assembling the parts of the reduction gear both a vibration damper setting jig and an alignment marker are necessary. With these it is essential to use the following sequence of operations:

Place the reduction gear on the work table, flanged side up, inserting two reduction gear flange bolts which will facilitate locating index marks as the assembly is built up. Next, place the inner propeller shaft and flange in position on the reduction gear, indexing the "0" marks on both flanges. Then place the outer propeller shaft over the inner propeller shaft, aligning the wide spline of the inner shaft with the locating pin of the outer shaft. Figure 21 shows the order in which the plates are assembled.

The friction vibration damper outer member plates and spring are then assembled as a unit before installation on the inner and outer shaft assembly. To do this, place the outer member, flanged side up, on the work table, to receive the plates and spring. Each vibration damper friction plate is numbered on one side; the numbers face up as they are installed in the vibration damper outer member and index in the order shown. Coat the

inner surface of the outer member with regular engine oil and each succeeding steel and copper plate and spring as installed is also oiled.

The vibration damper assembly is then placed in position on the inner and outer shaft assembly. Care should be taken to prevent movement between plates. Locate the assembly by indexing the "0" mark on the spline at the rear of the outer shaft with an "0" mark on the vibration damper copper plate. The operation of installing the vibration damper plate assembly with the outer shaft in position is necessary to provide accurate locating of the copper plate splines before installing and tightening the remaining reduction gear flange bolts. These bolts are next tightened uniformly and aligned so that the pins can be conveniently installed after the assembly is removed from the tension setting jig.

Now remove the outer propeller shaft and install the assembly comprising the inner shaft, the vibration damper, and the reduction gear as one assembly in the jig, making sure that the "0" mark in the fixture indexes with the

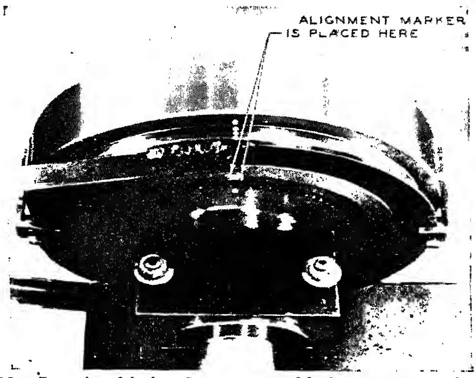


Fig. 22.—Locating friction damper assembly in pressure setting jig.

"0" marks on the damper assembly. Next place the alignment marker in the tooth of the jig marked "0." Check to see that the scribe lines on the pressure plate are absolutely in line with the edges of the marker tool, as in Fig. 22.

If these lines should be off as much as 0.010 in., place the marker tool in any tooth on the jig, and scribe new lines on the pressure plate and use this marking as your original damper position. Be sure to mark the tooth in the jig that is being used for the new mark. Vibration damper pressure is correctly set when a load of 93 to 107 lb. on the 30-in. extension arm (Fig. 23) will cause the damper to slip. To increase pressure, the mounting face of the outer member flange can be surface ground. To decrease pressure, the flange of the rear pressure plate that bears against the spring must be surface ground. Removal of 0.001 in. of surface will change the pressure approximately 2 lb. (60 in.-lb.). After the damper is correctly set, install cotter pins in the flange coupling bolts. Before removing the assembly from the fixture, insert the marker tool with the corresponding "0" mark on the jig and lift up on the extension arm to bring the scribe marks on the pressure plate to correspond with the alignment marker.

Reduction Gear Assembly.—Apply engine oil to the inside and outside of both propeller shafts before assembling. Install the inner propeller shaft in the outer shaft, making certain that the milled slot on the front end is aligned with the pin in the outer shaft. This alignment pin on the front of the shaft will locate the rear spline of the outer shaft properly with the splines of the copper disks. Tighten the inner propeller shaft nut, and install the cotter pin so the head will take the load. Next drop the copper gasket in place inside the outer shaft and insert the oil transfer tube. Insert the sleeve and tap the outer propeller shaft plug into place against the sleeve.

The thrust bearing, oil seal, oil-seal washers, spacer, etc. (see Fig. 24), must be assembled on the propeller shaft in the following sequence:

Slip the oil-seal fittings over the oil-seal inlet tubes and bolt the fittings and oil seal to the rear face of the thrust bearing retainer (Fig. 25).

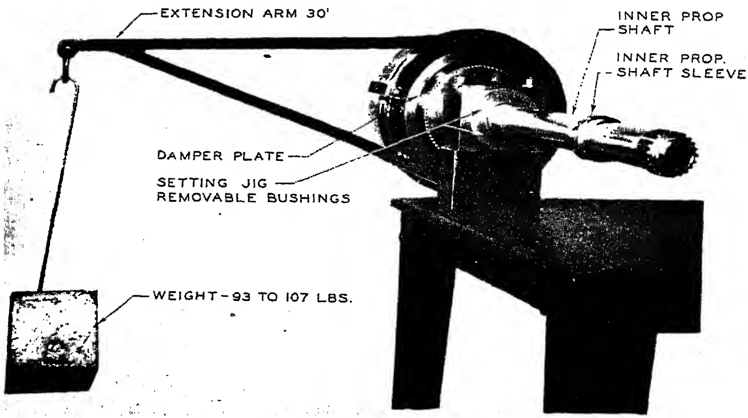


Fig. 23.—Apparatus for checking damper pressure.

Place the oil-seal washer on the propeller shaft with the bronze face to the front. Lubricate the face of the washer with engine oil, and then place the oil-seal spacer in position.

Next place the oil-seal and thrust bearing retainer over the oil-seal spacer with studs to the front. Lubricate the second washer and press it down snug against the spacer.

The thrust bearing should be warmed slightly and put on the shaft next. Apply a small quantity of petrolatum to the ball bearing as a protection against rust. The oil slinger is next placed over the shaft and bears on the inner race of the bearing. Then coat the threads of the thrust nut with Lubriplate and tighten.

The clearance between the oil seal and the oil-seal washers should be checked with the table of limits.

Install the breather and oil-pump assembly on the reduction gear case. Apply a coating of engine oil to the whole propeller shaft assembly.

To install the propeller shaft assembly in the reduction gear case, the following procedure should be followed:

Note: In order to avoid interference with the thrust bearing assembly, the governor pad bushing and governor drive shaft should not be installed in the reduction gear case before installing the propeller shaft..

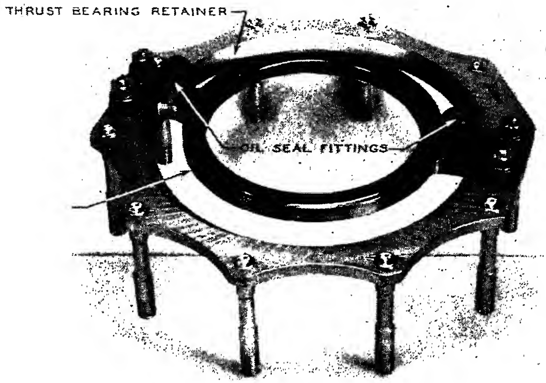


FIG. 24.—Thrust bearing retainer and oil-seal assembly.

One stud in the thrust bearing retainer is located off center. Stand the propeller shaft assembly in a vertical position, place the reduction gear case over the shaft, and locate the studs in position.

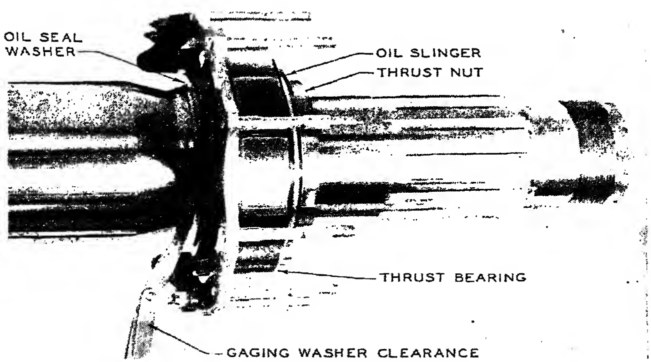


FIG. 25.—Installing the thrust bearing.

Install the cover plate and stud spacers. Tighten the ten attaching nuts and palnuts.

Install the governor drive shaft, bushing gasket, pad bushing, cover gasket, and cover.

The bar is then attached to a suitable universal drive, to avoid flexing of the boring bar or holding the fixture from alignment. Be sure to open the drip cups to lubricate the three alignment bearings. The bearings are bored at a speed of 24 r.p.m. with 0.007-in. feed per revolution. The cut is made from the accessory housing end toward the front of the crankcases.

When the crankcases are separated after finish boring, the bearing halves are removed and a relief is cut in the bronze between the two oil grooves. The relief is cut 0.002 to 0.004 deep by 1/4 in. wide using a special relieving tool. There are also two types of tapered reliefs cut into the bronze at the edges of the bearings. These reliefs are known as types A and B, type A being 0.002 to 0.004 deep by 5/32 in. long and type B 0.004 to 0.006 deep by 3/16 in. long. Both edges of the center main bearing (No. 4) are cut with type A relief, using the center main bearing edge relieving tool. The remaining main bearings are cut with type B relief on the edges facing No. 4 and type A relief on the opposite edges using the main bearing edge relieving tool made for this work. The edges facing No. 4 are the front edges for bearing Nos. 1, 2, and 3, and the rear edges for bearing Nos. 5 and 6. The rear edge of the bearing can be distinguished from the front since the part number is always etched on the O.D. of the bearing rear flange. The bearings and their corresponding reliefs are as follows:

Bearing number	Type relief*	
	Rear	Front
1	A	B
2	A	B
3	A	B
4	A	A
5	B	A
6	B	A

* A = 0.002 to 0.004 in. deep by 5/32 in. long.
B = 0.004 to 0.006 in. deep by 3/16 in. long.

Crankshaft Main Bearing Replacement.—The first operation in installing a new crankshaft main bearing is to "black in" the bearing in accordance with usual overhaul procedure used on crankcases and bearings of "in line" engines.

After all bearings are "blacked in," they are cleaned and installed in crankcases. Install the roller-bearing cage. Tighten all the main bearing nuts to the same tension used for the final assembly, and install every other nut on the crankcase parting flange. Scrape the paint from the edge of the lower crankcase parting line flange.

The crankcases are then installed in the holding fixture with the accessory housing end toward the end of the fixture marked "accessory housing end." The end of the center main bearing should clear the face of the boring bar center support by approximately 1/8 in. The crankcases are held in the fixture with four clamps which are clamped over the hold-down bolt boss. Insert the boring bar in the fixture with the drive end toward the accessory housing end of the crankcases.

The boring bar has six cutting blocks numbered one to six, which are installed in the locating slots of the boring bar which are also numbered to correspond with the bearing numbers of the crankcase. Each cutter consists of a steel block having two adjustable inserts diametrically opposite each

other. The cutting insert is a Carboloy tipped tool; the other insert is a plain blade used only as a micrometer guide. Indexing the numbers on the blocks with those on the bar will locate the cutting blades 180 deg. apart. The dummy blade is set to approximately $\frac{1}{32}$ in. less radius than the cutting blade.

Measure the diameter of the crankshaft main journal corresponding to the bearing to be bored. The smallest diameter of the measured journal is taken and added to the lower clearance limit given in the table of limits (page 32) which will give the desired finish bore diameter. The cutter is then adjusted for this diameter and installed in the bar, located, and indexed as outlined above. It may be necessary to take one preliminary cut to determine the cutting diameter. The cutter can then be adjusted to the desired finish bore diameter. Make sure that all slots are clean before installing the cutting blocks in the boring bar.

FINAL ASSEMBLY AND TIMING

All painted and enameled parts of the entire engine should be inspected closely for defects before the final assembly. All spots should be retouched with the proper paint or enamel.

Parts, such as bearings, pistons, and connecting rods, are numbered on the accessory housing side and should be so installed. Other parts, such as bearing cages and camshafts, are marked to indicate proper installation. Figure 19 shows markings on the connecting rods; Fig. 21 shows marking of parts in the vibration damper assembly.

All moving parts should be well coated with regular engine oil on assembly. External steel parts should be covered with grease to prevent rust.

All nuts must be either cottered, locked with tab washers, or locked with palnuts. Cap screws that have drilled heads are locked by safety wire. The cotters should be installed so that, if loading exists, the head end will take the load.

All tab washers, piston pin retainers, rubber packing, rubber hose, composition gaskets, cotter pins, and locked wires must be replaced during major overhaul.

It is important that all parts be thoroughly cleaned and that no dirt be permitted to enter the engine during assembly.

Gasket paste, medium weight, Titeseal, is used on all parting surfaces during the final assembly except where composition gaskets are used, or as otherwise specified herein. The Mica and Oil solution may be used on all composition gaskets.

Crankshaft, Connecting Rod, and Crankcase Assembly.—Mount the upper crankcase on the assembly stand and rotate it until the case is inverted. Place the long accessories drive shaft in the tunnel of the upper crankcase. The driving gear is placed on the shaft. Install the tab washer and tighten the nut. Install the main bearing upper halves with numbers toward the accessory housing end of the engine. Figure 26 shows the method.

Place the outer race and bearing cage in position on the shaft. Use the crankshaft sling shown and lower the complete crankshaft and connecting rod assembly into position in the upper crankcase (see Fig. 27). Do not let the outer race slip off the bearing, and see that the bearing cage is fitted over the locating dowel in the case. The forked rods are placed in the right bank and the blade rods in the left (see Fig. 19).

Next place the plain reduction gear bearing into position in the upper crankcase. The bearing should be drawn up snug with the crankcase face

by tapping with a fiber driftpin. Align the dowel hole and install the threaded dowel through the upper crankcase.

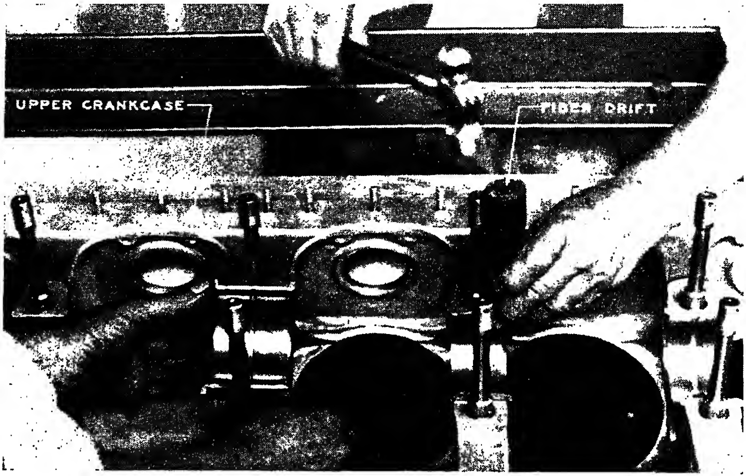


FIG. 26.—Installing main bearings in crankcase.

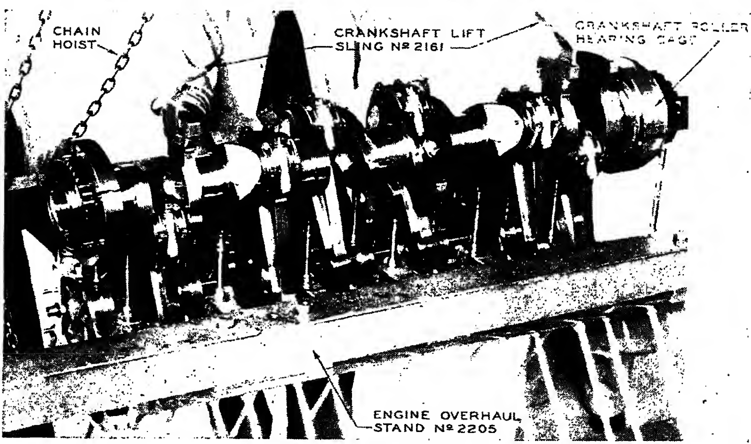


FIG. 27.—Lowering crankshaft assembly into upper crankcase.

Place the main bearing lower halves in the lower half of the crankcase. The bearings should be carefully fitted over the dowels. Apply a sufficient

amount of heavy oil to prevent the bearing halves from dropping off the dowels.

Coat the parting surface of the upper crankcase with gasket paste, medium weight, Titeseal and lay a No. 50 silk thread along each side of the case. The lower case is then placed in position by hand (see Fig. 28).

Install and tighten all main bearing nuts securely, but not excessively. Then the tension is adjusted by loosening each nut, one at a time, and tightening it through an angle of 90 deg. after it just makes contact with the lower half of the crankcase boss. If a calibrated torque wrench is used, the proper tension is 700 to 800 in.-lb. of torque. Install and tighten all washers, nuts, and palnuts around the crankcase parting flange.

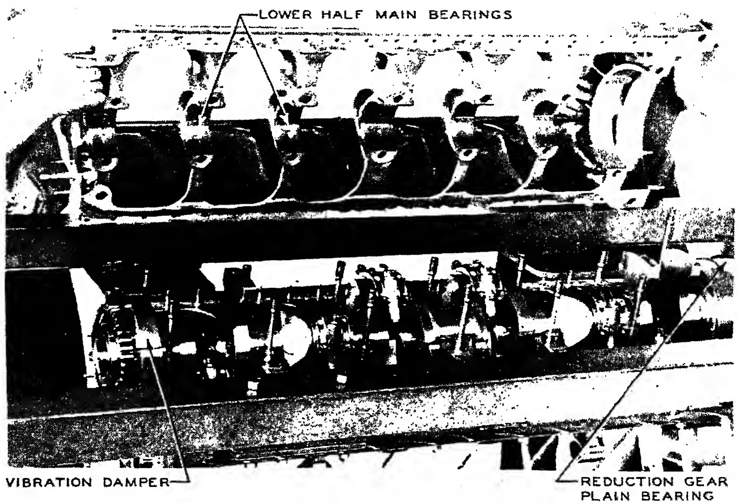


FIG. 28.—Placing lower crankcase in position.

Accessory Housing Installation.—Rotate the stand 180 deg. so that the crankcase assembly is in the normal upright position.

Coat each side of the accessory housing gasket with gasket paste, medium weight, Titeseal. Install a new rubber gasket around the crankcase oil tube and make sure the gasket is in position. Install the gas intake pipe adapter on the accessory housing. Attach the accessory housing lift ring to the two magneto studs and hoist the accessory housing assembly into position and mount it on the crankcase; install the nuts and palnuts. *Do not overlook installing the two nuts inside the crankcase on the two accessory housing studs.*

Place the upper camshaft drives in the lower drive housings and push into accessory housing until the splined end bears on the end of the lower drive spline. Do not tighten the packing nut. Insert the two long cap screws in each upper drive housing. These cap screws must be installed before the cylinder blocks are mounted, since clearance will not permit their installation

with cylinder blocks in place. Coat the upper drive flange with gasket paste, medium weight, Titeseal.

Propeller Reduction Gear Assembly.—Coat the surface of the reduction gear mounting face with gasket paste, medium weight, Titeseal and place No. 50 silk thread on face for seal. Use the lift sling to install the reduction gear assembly in position and to hold the weight off the plain bearing until the assembly is started on studs. Do not bring the housing in complete contact with the crankcases, but draw it the last 3/8 in. by tightening the nuts on the studs. This avoids the possibility of disturbing the thread seal.

Pistons and Cylinder Block. *Right Bank.*—A complete new set of piston rings will be installed at each overhaul. Install new rings on the right bank pistons. These engines have five rings to each piston. Three compression-

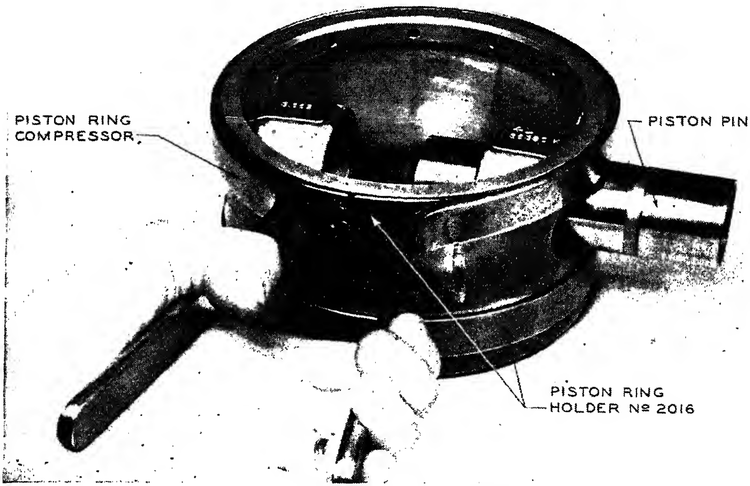


FIG. 29.—Using special piston ring fixture.

type rings are located in the upper piston grooves. Dual oil rings are installed in the one groove below the piston pin. Any other ring arrangement existing at disassembly will be converted to the combination existing in the current assembly parts list.

Align the gaps of the rings so that they are staggered 180 deg. All gaps should be located on the piston-pin side of the pistons, at either end of piston pin.

Install 12 piston-ring holders (seen in Fig. 29) over the rings using the piston-ring compressor. One holder is located to cover the three compression rings and one to cover the oil rings. Coat each side of the cylinder-barrel bearing plates with gasket paste, medium weight, Titeseal, and install screws holding them in place on the crankcase.

Install the pistons on the connecting rods, as in Fig. 30, and insert the snap ring piston-pin retainers in place. The retainers should be securely

seated in the grooves provided in the pistons, and it is *extremely important that none are omitted.* Check all retainers to see that they are properly seated in the grooves.

Rotate the stand until the cylinder hold-down bolts of the right bank are vertical. Turn the crankshaft with the propeller shaft wrench so that pistons 1 and 6 are at their highest point and cylinders 2, 3, 4, and 5 are even. The crankshaft is kept in this position during the installation of the cylinder block.

Using the cylinder block lift sling and chain hoist, lower the cylinder block over the pistons and start hold-down studs into the head. Three men are required to perform this operation: one to operate the chain hoist and two to guide the pistons into place (see Fig. 31).

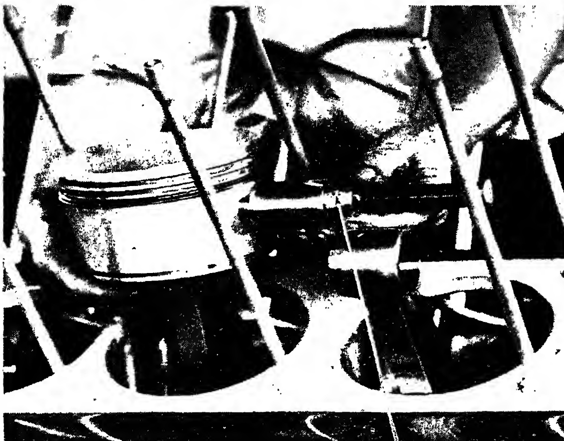


Fig. 30.—Putting pistons on connecting rods.

When the cylinder barrels are lowered far enough that the compression rings of pistons 1 and 6 have entered the cylinder barrel, the top holders are removed. The cylinder block is lowered farther with the crankshaft in the same position, until the barrels have just covered the compression rings cf pistons 2, 3, 4, and 5. This will leave enough space to remove these piston ring holders before they are pushed into the crankcase. The bottom holders on cylinders 1 and 6 will be pushed off by the cylinder barrels. Lower the block down to the pressure plate and remove the four bottom holders of pistons 2, 3, 4, and 5 from inside the crankcase. Be careful in removing the piston-ring holders from the crankcase to avoid scratching the connecting rods.

Install nuts on the cylinder hold-down studs. *To minimize high-temperature strains in these parts,* the following method of tightening these nuts must be observed:

Begin with the center studs and work toward each end; tighten all nuts evenly until they are tight. This is done to seat the block firmly and to

remove any burrs or other obstructions under the washers. Next, loosen one nut at a time, and turn it down until it makes contact again with the boss, but do not load the stud. Then tighten by turning through an angle of 90 deg. Cotter each nut after the final tightening. After the block test run with the engine *cold,* the nuts should be reset as outlined above as there is a tendency for the block to settle during the initial running.

The upper camshaft drives are drawn up into position and attached to the cylinder block with the four cap screws. Press the lower packing gland into the lower camshaft drive housing and tighten the packing nut with the fingers, using the service tool wrench to turn the nut 90 deg.

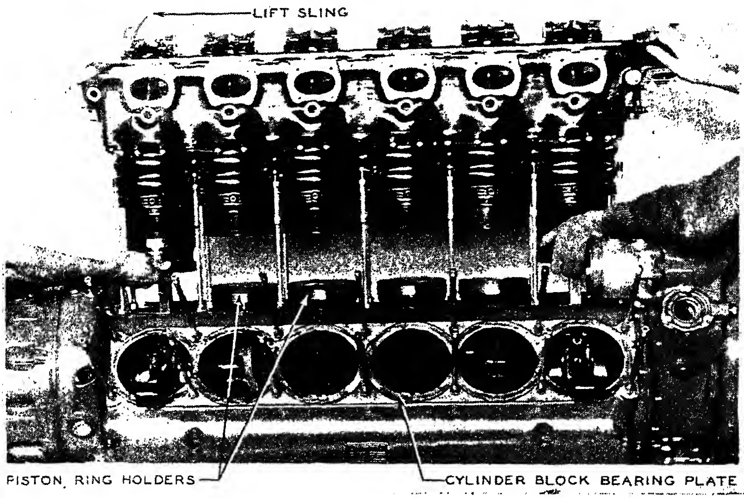


Fig. 31.—Lowering right-hand cylinder block on crankcase. This takes three men.

Caution. Unless this procedure is followed, the packing will be forced too far into the housing and cause excessive oil leakage. Replacement of the packing necessitates removal of the cylinder block.

Left Bank.—Follow the same procedure to install the left-bank pistons and cylinder block.

Intake Pipe and Manifold Assembly.—Install the backfire screens and tees in the center gas-intake pipe. Install the rubber connection and large clamp on the gas-intake pipe adapter. Install the gas-intake pipe and pipe tie strap, being sure to locate the primer line T fitting, and insert the cap screw. Install one rubber connection and two clamps on each tee outlet. Install manifold gaskets and manifolds, being sure to place primer tube clips beneath the cap screws in the top flanges of the manifolds. Do not tighten the manifolds at this time. Locate the manifolds on the studs to align with the tees. Tighten the cap screws, nuts, and install palnuts. Slip the rubber connection and clamp from the tee to each manifold. Tighten all

rubber connection clamps. Tighten the gas-intake pipe, tie-strap cap screws, and safety.

Distributors and Ignition Shielding.—After the distributors and ignition shielding assembly are overhauled and assembled according to directions, they are placed as a unit on the engine. Installation on engine and diagram for electrical connections are given on pages 9 and 10.

Oil Pan.—Install the oil-pan gasket and attach the oil pan to the lower crankcase and accessory housing. Be sure to install the two castellated nuts and cotter pins *inside the front of the oil pan.* Tighten the nuts at each end of the pan first. Install the reduction gear drain elbow gaskets, using Mica and Oil solution and mount the drain elbow with the four washers, plain nuts, and palnuts to the oil-pan studs; then install the washers, the two long and two short cap screws to the reduction gear housing and lock.

Coolant Pump.—Install the coolant pump on the bottom of the accessory housing. The overhaul of the coolant pump is easily done by any good mechanic. The coolant pump is installed with one outlet facing to the left side of the engine, and the face of the other flange toward the front of the engine on the right side.

Coolant Pipes.—After the coolant pipes are cleaned and inspected, assemble the elbows and center pipes, using new hose connections. Slip the hose clamps in position but do not tighten them. Install gaskets and attach the flanges to the coolant inlet manifold flanges. Tighten the rubber hose connections next.

Timing the Engine. *Valve Timing.*—Set the tappet clearance to 0.010 in. for intake, and 0.020 in. for exhaust valves of cylinders 6L and 1R. When this is done, be sure that the cam rollers are on the heel or base circle of the cams. The timing disk is on the starter shaft and the top center indicator is put in the intake spark-plug bushing of cylinder 6L. Rotate the propeller shaft and set piston 6L on top dead center (T.D.C.). Adjust the pointer on the timing disk to T.D.C. to agree with the piston position.

The propeller shaft revolves in a clockwise direction when viewed from the rear or starter end of the engine. The starter shaft and timing disk pointer revolve in the opposite direction. Therefore, the timing disk pointer turns in the counterclockwise direction for clockwise rotation of the propeller shaft. This was shown in Fig. 3.

Turn the propeller shaft in the *counterclockwise* direction approximately 90 deg., and then clockwise until the pointer registers 52 deg. B.T.C. (before top center). Turn the left-bank camshaft with the bevel gear removed until the intake-tappet clearance of cylinder 6L is just taken up and the valves are beginning to open.

Adjustment of the valve timing is obtained by altering the angular relation between the camshaft bevel drive gear and the camshaft. The camshaft gear has 36 teeth, and is attached to the camshaft flange by seven bolts, which allows a variation of approximately 3 deg. at the crankshaft.

Install the beveled camshaft gear so that the seven bolt holes line up with the flange on the camshaft. Fasten two bolts in place and rotate the propeller shaft clockwise until the exhaust valves of No. 6L close. The exhaust valve closing position should be 26 deg. A.T.C. (after top center). If this position does not check, the camshaft should be adjusted so that the differences of the intake opening position and the exhaust closing position from the specified values are about equal. The intake opening time should be within ± 1 deg. of specified value; the exhaust closing time should be within ± 3 deg.

The remaining five bolts may now be fastened in place in the beveled drive gear. Install the nuts, tighten, and cotter.

The right-bank valves are next timed. Turn the propeller shaft clockwise until the timing disk reads 60 deg. A.T.C., which is the T.D.C. position of piston 1R. Since the intake valve should open 52 deg. before top center, the propeller shaft is turned in a counterclockwise direction 52 deg., which will read 8 deg. A.T.C. on the timing disk. *Always approach the timing position by a clockwise rotation of the propeller shaft.* Then set the right-bank camshaft so that the intake valves of cylinder 1R are just beginning to open and attach the camshaft gear as before. Turn the propeller shaft clockwise to the exhaust valve closing position and read the timing disk. This reading should be 86 deg. A.T.C. which is 26 deg. after T.D.C. position of cylinder

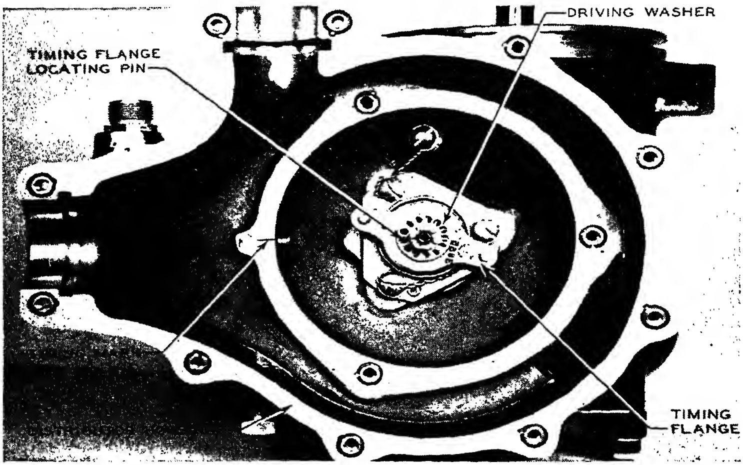


Fig. 32.—The distributor head timing flange.

1R. Divide the difference between the intake opening and the exhaust closing position as just mentioned.

The valve tappet clearances of the remaining intake valves are set to 0.010 in. and the tappet clearances of the other exhaust valves to 0.020 in. These clearances are the normal cold tappet adjustment for engine operation.

Magneto Timing.—Rotate the propeller shaft in a clockwise direction so that the timing pointer reads 35 deg. B.T.C. on the compression stroke of cylinder 1L. In this position, both the intake and exhaust valves of cylinder 1L are closed. If either of these valves is open, an error has been made in the valve timing or the crankshaft is 360 deg. out of phase for the magneto timing operation.

Remove the magneto breaker cover to install the timing clamp tool on top of the breaker cup. Locate the straight edge of the tool against the shoulder of the step cut on the adjustable cam cap, then align the straight edge with the two diametrically located marks on the breaker cup diameter. Next set the magneto on the engine with end marked "EXH." toward the

front. If the magneto does not drop into the coupling spline and locate within 5 deg. of the engine center line, remove it. The magneto coupling member is then removed from inside the magneto drive shaft and relocated until the required alignment is obtained. Fasten the magneto in position on the flange studs and remove the clamping tool. The magneto will then be engaged with the drive coupling member so that it is possible to open the contact points when the magneto is turned through the angle provided by the curved slots in the flange. Insert a strip of thin cellophane paper (about 0.001 in. thick) between the exhaust breaker points, and carefully adjust the position of the magneto until the points start to open as indicated by the slipping of the cellophane paper. The magneto may then be securely fastened in position. The timing between the exhaust and intake firing

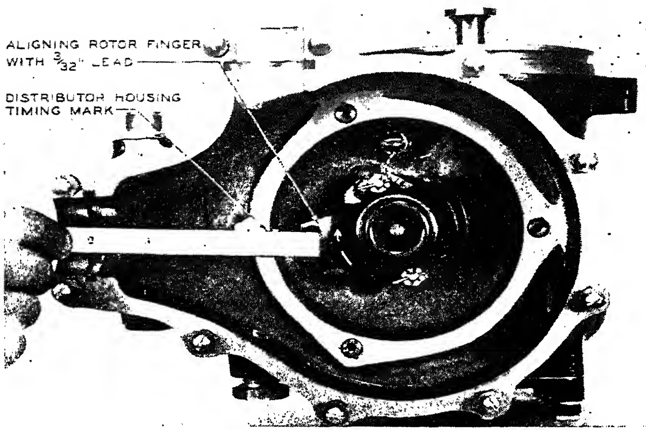


Fig. 33.—Timing the distributor rotor.

positions is fixed by the magneto design at 6 deg.; however, it is necessary to check the intake side of the magneto to be certain the magneto is functioning properly. The intake should break at 29 deg. B.T.C.

To check the timing, turn the propeller shaft so that the indicator reads about 50 deg. B.T.C. and insert a strip of cellophane paper between the exhaust magneto breaker points. Turn the propeller shaft clockwise slowly to determine the position at which the contact breaker point opens, which should be 35 deg. B.T.C. The magneto mounting nuts can be loosened and the magneto tapped slightly in a clockwise direction to give a later timing if this check shows that the points are breaking early; counterclockwise if they are breaking late.

Distributor Rotor Timing.—Since the distributor rotors are geared to the camshaft, it is necessary that each rotor be individually timed. When the valve timing has been completed, each distributor rotor assembly is mounted on the cylinder blocks for ignition timing operations. *The right-bank rotor supplies the ignition to all the exhaust spark plugs and the left-bank rotor to all the intake spark plugs.*

Table 1.—Wear Limits

Description of limit	Min.	Max.
Accessory drive shaft in bushings, diam	0.003L*	0.005L
Accessory drive-shaft bushings in crankcase, diam	0.0015T*	0.003T
Crankshaft in main bearings (after bearings are clamped in crankcase), diam	0.0040L	0.0050L
Reduction gear in large plain bearing:		
Diam., front	0.0145L	0.0185L
Diam., rear	0.020L	0.025L
Piston pin in piston, diam	0.000	0.0008L
Piston in cylinder—bottom	0.015L	0.019L
—top	0.030L	0.034L
At 2d ring land, diam	0.024L	0.028L
At top of skirt, diam	0.020L	0.024L
Piston Ring:		
Top ring, side clearance	0.0065L	0.008L
2d ring, side clearance	0.005L	0.0065L
3d ring, side clearance	0.002L	0.0035L
4th and 5th ring, side clearance	0.002L	0.005L
Top compressed gap	0.020	0.028
2d compressed gap	0.020	0.028
3d compressed gap	0.020	0.028
4th and 5th rings, gap	0.020	0.028
Intake valve stem in guide, diam	0.002L	0.0035L
Exhaust valve stem in guide, diam	0.003L	0.0045L
Valve spring outer:		
Open (compressed to 1$\frac{5}{16}$ in.)	77 lb.	79 lb.
Closed (compressed to 1$\frac{13}{16}$ in.)	33 lb.	37 lb.
Valve spring inner:		
Open (compressed to 1$\frac{3}{16}$ in.)	47 lb.	51 lb.
Closed (compressed to 1$\frac{11}{16}$ in.)	18 lb.	22 lb.
Camshaft in locating bearing (bearing compressed 0.000 to 0.0015), diam	0.0025L	0.006L
Camshaft in locating bearing, end play	0.006L	0.009L
Camshaft in bearings (bearing compressed 0.000 to 0.0015), diam.	0.0025L	0.005L
Piston pin bushing in rod, diam	0.0015T	0.003T
Piston pin in rod bushing, diam	0.0015L	0.0023L
Connecting rod bearing on crankpin, diam	0.004L	0.005L
Blade rod in forked rod, end clearance	0.005L	0.009L
Roller bearing:		
In cage† diam	0.001L	0.005L
On crankshaft, diam	0.000	0.001T
Propeller shaft steady bearing on inner shaft flange, diam	0.0015L	0.003L
Reduction gear oil pump:		
Drive shaft in large bushing, diam	0.002L	0.0035L
Drive shaft in intermediate and front bushing, diam	0.0015L	0.003L
Gear to governor drive gear, backlash	0.003	0.018
Gears, backlash	0.0035	0.0075
Idler bushing in gear, diam	0.001T	0.003T
Idler gears on shaft, diam	0.001L	0.0025L
Propeller shaft oil seal washer and seal side clearance	0.001L	0.0025L
Supercharger impeller shaft:		
Bearings in cage, diam	0.0015L	0.0025L
In bearings, diam	0.002L	0.003L
Locating bearing, end play	0.029L	0.035L
Front bearing, end play	0.025	0.095
Super. impeller to drive housing face, end clearance	0.023	0.041
Super. drive gear in bearing, diam	0.0002T	0.0014T
Super. drive gear bearing in cage, diam	0.0002L	0.0018L
Upper camshaft drive shaft in bushing, diam	0.0015L	0.003L
Tachometer shaft in bushing, diam	0.001L	0.0025L
Super. impeller to inlet cover (with impeller forward) (selective), end clearance	0.035L	0.055L
Lower camshaft drive gear in housing bushing, diam	0.002L	0.0035L
Accessory extension shaft:		
In main accessory shaft, spline sliding fit	0.000	0.001L
Bearing in cage, diam	0.0002L	0.0018L
In bearing, diam	0.0001L	0.0009T
Bevel gears, backlash	0.003	0.009
To supercharger drive gear, spline sliding fit	0.000	0.001L

* The letters L and T mean "loose" and "tight" by the amount shown.

† When cage is compressed in crankcase at room temperature (compression 0.0025 to 0.004).

Table 1.—Wear Limits (*Continued*)

Description of limit	Min.	Max.
Magneto drive shaft:		
In bushing, diam.	0.002L	0.0035L
In gear, spline slip fit	0.000	0.002L
Magneto drive cluster gear, lower camshaft drive gear, backlash	0.003	0.018
Magneto coupling shaft in drive shaft, spline slip fit	0.000	0.002L
Magneto coupling on magneto coupling shaft, spline slip fit	0.000	0.002L
Magneto coupling on magneto, spline slip fit	0.0005L	0.0025L
Starter shaft:		
Roller bearing in cage, diam.	0.0007L	0.0023L
In roller bearing, diam.	0.000	0.0007L
Ball bearing in cage, diam.	0.0002L	0.0018L
In ball bearing, diam.	0.0001L	0.0008T
Jaw on shaft, spline slip fit	0.000	0.002L
Spur gear, backlash	0.006	0.012
Pump gear, backlash	0.003	0.018
Gears on shaft, spline slip fit	0.000	0.001L
Generator and pump:		
Drive cage in accessory housing, diam.	0.0005T	0.0015L
Drive shaft in housing, diam.	0.002L	0.0035L
Drive gear, backlash	0.003	0.009
Generator shaft bearing:		
In cage, diam.	0.0002L	0.0018L
On shaft, diam.	0.0001L	0.0006T
Generator shaft in bushing, diam.	0.0015L	0.003L
Vacuum pump drive shaft:		
In bushing, diam.	0.0015L	0.003L
Spur gears, backlash	0.003	0.007
Oil pump shaft:		
In long bushing, diam.	0.0015L	0.003L
In short bushing, diam.	0.001L	0.0025L
Oil pump drive gears on shaft, spline sliding fit	0.000	0.0015L
Oil pump idler gears on shaft, diam.	0.001L	0.0025L
Coolant pump:		
Bearings on shaft, diam.	0.0002T	0.001T
Shaft in impeller sleeve, spline light tap	0.0005T	0.0004L
Packing spacer on shaft, diam.	0.001L	0.003L
Distributor driven shaft:		
Bearings in cage, diam.	0.0002L	0.0012L
Bearings on flange, diam.	0.0002L	0.001L
Distribution idler gear on shaft, diam.	0.001L	0.0025L
Gun impeller generator drive shaft in bushings, diam.	0.0015L	0.003L
Distributor finger in head (main) (including eccentricity of 0.0095), gap	0.0105	0.054
Distributor finger in head (booster) (including eccentricity of 0.0095), gap	0.0175	0.061
Gun impulse generator:		
Rear bearing in housing, diam.	0.0002L	0.0017L
Bearing on coupling hub, diam.	0.0001L	0.0009L
Bearing on cam hub, diam.	0.0001L	0.0009L
Impeller generator cam:		
Follower in housing, diam.	0.001L	0.0025L
Roller on follower, diam.	0.0005L	0.002L
Oil tube in impeller generator shaft, diam.	0.0005T	0.002T
Intake valve seat in head, shrink fit	0.010T	0.013T
Exhaust valve seat in head (shrink fit):		
Small diam.	0.005T	0.008T
Large diam.	0.003T	0.005T
Cylinder barrel in head, shrink fit	0.024T	0.027T

Rotate the propeller shaft so the timing pointer reads 35 deg. B.T.C. on the compression stroke of left cylinder 1. Remove the two cotter pins and two castellated nuts, and remove the rotor. Remove the cotter pin and castellated nut from the timing flange, then the driving washer and pin. Place the driving washer in position on the timing flange without the pin and place the rotor in position. Rotate the rotor so that the leading edge of the thick rotor finger will be 3⁄32 in. past or beyond the "mark" on the distributor rotor drive housing. Carefully remove the rotor, *and do not*

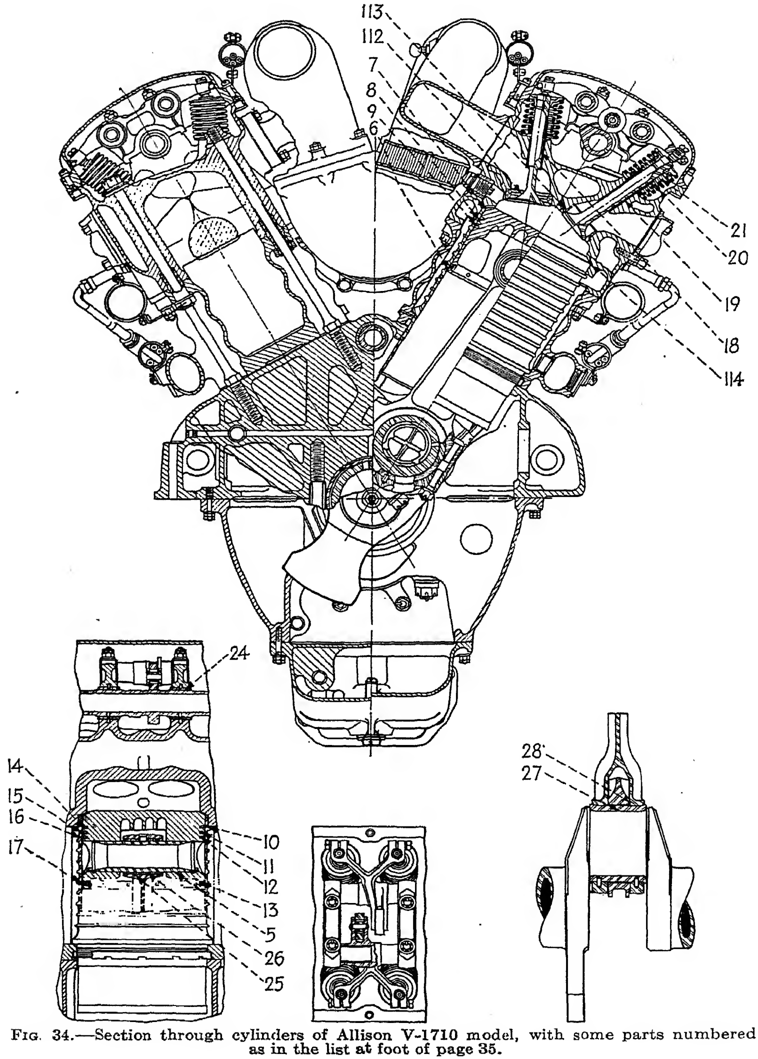


FIG. 34.—Section through cylinders of Allison V-1710 model, with some parts numbered as in the list at foot of page 35.

disturb the timing flange or driving washer. Locate the matched holes in the timing flange and driving washer, and mark them with a pencil, as in Fig. 32. Remove the driving washer and insert a pin in the hole that is pencil-marked on the timing flange. Install the driving washer, indexing the holes with pencil marks. Install a castellated nut, and tighten. Place the rotor in position and check the position of the pointer on the timing disk. The timing is correct if the pointer reads 35 deg. B.T.C. Remove the rotor and install a cotter pin in the timing flange castellated nut. Install the rotor, two castellated nuts, and the cotter. The intake rotor (left hand) is then adjusted with the timing pointer set at 29 deg. B.T.C. (intake firing position) so the finger is aligned with the mark, as outlined above (see Figs. 32 and 33).

PERMISSIBLE WEAR LIMITS

The Allison Engineering Co. provide a very complete list of wear limits covering nearly 400 parts. For general overhaul purposes, the list on pages 32 and 33 will be found all that is necessary. This table gives minimum and maximum working clearances, and also the amount of tightness (marked "T") where press fits are used. In most running fits the parts should be replaced when the clearance exceeds the maximum by 0.0005 to 0.001 in.

Figure 34 shows one of the charts used in connection with these wear limits, with the parts indicated. This does not show all of the parts listed; but in addition to showing some of these parts, it gives an excellent cross section of the engine.

Key to Parts Shown in Fig. 34.

5. Piston pin in piston
6. Piston in cylinder, bottom
7. Piston in cylinder, top
8. Piston in cylinder, at second ring land
9. Piston in cylinder, at top of skirt
10. Piston ring, top ring, side clearance
11. Piston ring, 2d ring, side clearance
12. Piston ring, 3d ring, side clearance
13. Piston ring, 4th-5th rings, side clearance
14. Piston ring, top, compressed gap
15. Piston ring, 2d, compressed gap
16. Piston ring, 3d, compressed gap
17. Piston ring, 4th-5th, compressed gap
18. Intake valve stem in guide
19. Exhaust valve stem in guide
20. Valve spring, outer
21. Valve spring, inner
24. Camshaft in bearing
25. Piston pin bushing in rod
26. Piston pin in rod bushing
27. Connecting rod bearing on crankpin
28. Blade rod in forked rod, end clearance
112. Intake valve seat in head, shrink fit
113. Exhaust valve seat in head, shrink fit
114. Cylinder barrel in head, shrink fit

SECTION II

TWIN WASP ENGINES

The Pratt and Whitney Twin Wasp engine is one of the best known large engines in aircraft use. It has 14 cylinders, in two rows of seven each, with a nominal cylinder $5\frac{1}{2} \times 5\frac{1}{2}$ in., developing approximately 1,000 hp. at about 2,500 r.p.m. Although the Hornets are much more powerful, their construction is similar and the methods of inspection and maintenance set forth here apply to both engines. Figure 1 shows an engine fitted for a

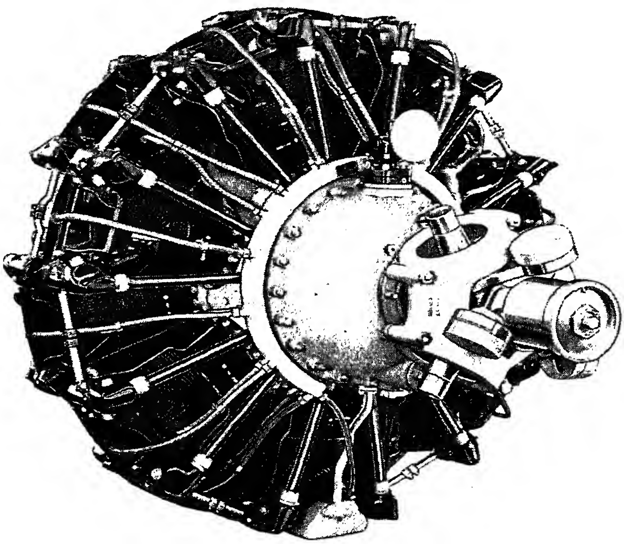


FIG. 1.—Fourteen-cylinder Twin Wasp—1,000 hp. at 2,500 r.p.m.

three-bladed, variable pitch, propeller hub. The diameter of the mounting ring is 27 in., the outside diameter is 48 in., and the length, without starter, about 60 in.

Overhaul periods depend on the way an engine is used. New operators of transport lines, and private owners, should not run more than 300 to 350 hr. for the first overhaul. Experienced users can run from 400 to 500 hr. before the first overhaul. The large transport lines run from 550 to 650 hr. between overhauls, after the first.

The methods of disassembly, inspection, repairs when necessary, and reassembly are those suggested by the makers of the engine.

Beginning with the engine stand (Fig. 2) the illustrations show the tools used and the way in which the work of overhauling is done. Where the illustrations are not mentioned in the text, the captions beneath make them clear.

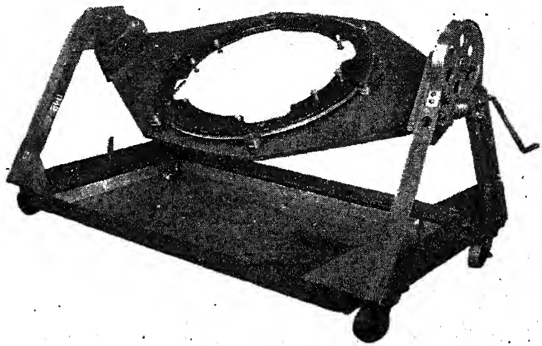


Fig. 2.—Engine stand for overhauling Twin Wasp engine. It permits the engine to be swung in any position.

Disassembly of the engine into subassemblies should be done in the following order:

1. Remove the spark plugs.
2. Check the propeller shaft runout.
3. Loosen the thrust nut *one* turn (Fig. 3).
4. Remove the ignition wires from the terminals.
5. Remove the distributor blocks from the magnetos by loosening the knurled coupling and screws on the manifold elbow. Raise the blocks vertically a short distance, then tilt them toward the rear of the engine to prevent the edge of carbon brush of the distributor from being broken on the edge of the magneto housing. Insert a wood block in place of the distributor block to keep dirt out of the magneto.

DISASSEMBLY OF ENGINE INTO SUBASSEMBLIES

Preliminary Operations.—It is very important that the disassembly of the engine be carried out with the prescribed tools and that the overhaul shop be equipped with a suitable engine stand, parts rack, and chain hoist, which should be of a 1-ton minimum capacity and so hung that it is, or can be, moved directly over the engine stand.

The engine is then turned so that it is in a vertical position with the rear toward the floor. Loosen the rear push rod cover tube inner glands, using the wrench, and remove the rear and front rocker box covers in the order named. This procedure will allow the oil from the valve lubricating system to drain into the rear rocker boxes and out of the inside end of the rear push

rod cover tubes. The rocker box covers are removed in pairs with the connecting intercylinder scavenge pipe. The intake rocker box cover on cylinder 7 and the exhaust rocker box cover on cylinder 9 are removed with the valve gear lubricating oil scavenge sump. To remove this sump, remove the oil scavenge line to the reduction gear housing and the two special studs which hold the sump to the rocker shafts of cylinder 8. Remove the closure plugs in the special rocker box covers on cylinder 8, and also the hollow drainage studs. The sump may then be removed with the rocker box covers of cylinders 7 and 9. Loosen the outer push rod cover tube glands.

Depress the rocker arm with the rocker arm depressor (Fig. 4) and remove the push rods and cover tubes. During this operation the propeller shaft is turned with the wrench, until the valves of the cylinder are closed, before depressing the rocker arm and removing the push rods of that cylinder.

The intake pipes are removed by loosening the packing glands at the blower end and at the intake port end with the wrench. When the packing glands have been loosened, the intake pipes are pushed to one side and a piece of 0.010-in. stock inserted between the end of the pipe and the connection on the cylinder. The pipe is then returned to its normal position and pulled radially from the blower section.

The oil scavenge pipes are dismounted by removing the nuts that hold them to the reduction gear housing and the rear section. Their retaining clamps are removed at the same time. Remove the oil scavenge pipe from the main oil sump and the oil pump. Remove the nuts and cap screw, holding the main oil sump in place, and then remove the sump from the engine. The oil drainage pipe (or pipes) from the power section will withdraw as the sump is removed.

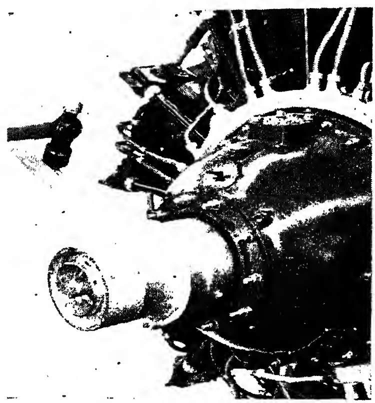


FIG. 3.—Loosening thrust nut by striking wrench with a hammer. It should only be loosened *one turn* until ready to remove.

Cylinders.—It is customary to remove all the cylinders of the front bank before removing the cylinders of the rear bank. (See Fig. 5.) Regardless of the procedure followed, the master rod cylinder of each bank should be the last cylinder of that bank to be removed.

Remove the palnuts first. The cylinder hold-down nuts are removed with a special wrench. Allow the top nut to remain on each cylinder until the nuts of the cylinders of that bank have been removed. The cylinders are then removed at one time. To do so, remove the top retaining nut and turn the propeller shaft with the wrench, until the piston is at the top of its stroke. The cylinder is then removed from the piston (Fig. 5). On C-3 engines, there may be some tendency for the spherical washers under the hold-down nuts to catch in the threads of the studs. It will be found that a quick jerk on the cylinder will break the washers loose from the studs.

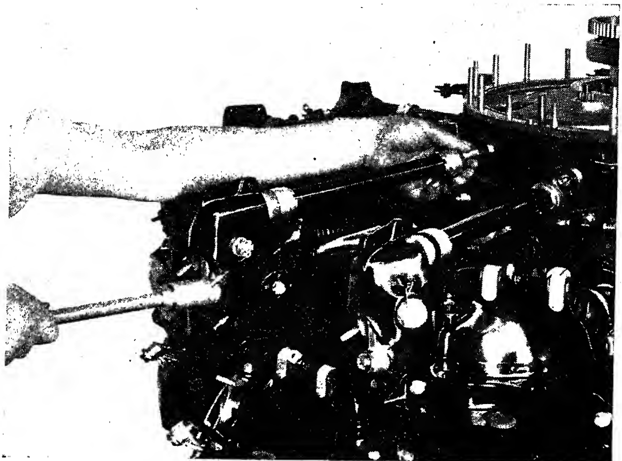


FIG. 4.—Depressing rocker arm with special tool.

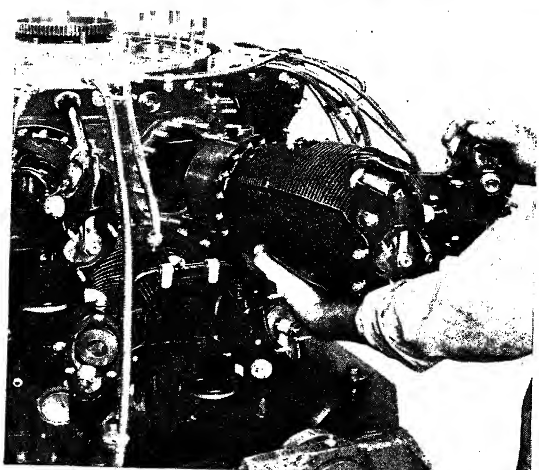


FIG. 5.—Removing a cylinder.

The piston pin and piston are removed from the link rod as soon as the cylinder is removed. Care should be taken to see that the piston pin does not fall out as the cylinder is being removed. The piston pin is a light push fit at room temperature. If the pin is difficult to remove from the piston, it may be pushed out with a fiber drift. The rod should be supported so that the knuckle pin or master rod bearing does not take the impact. Place a piece of fiber between the rod and the crankcase. Heating the head of the piston with a soft flame torch will facilitate the removal of the piston pin.

After the first cylinder and piston have been removed, the propeller shaft is turned so that the next piston is at the top of its stroke and the cylinder is

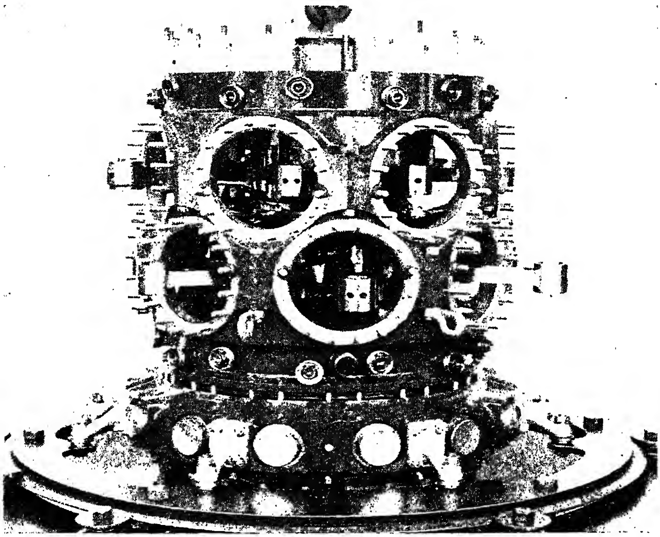


FIG. 6.—Power section crankcase.

removed in the same manner. *Leave the master rod cylinder until the last.* If this is not done, some of the pistons will withdraw from the cylinders enough to allow the oil scraper rings to expand below the end of the cylinder and the engine will become locked in this position. It should be remembered that the master rod with its piston is the guide for all the other rods and their pistons.

Ignition Manifold.—After the cylinders and pistons are out, the ignition manifold may be removed. It should be hung up so that it will not become soaked with oil or the casing dented.

When the nuts holding the reduction gear housing to the front main crankcase have been removed, the reduction gear assembly may be removed from the engine with the aid of the lifting eye.

After unlocking the drive gear nut on 3-2 geared engines, the nut is removed with the wrench, guided by the pilot which screws into the end of

the crankshaft. The drive gear is removed with the puller, which is in two parts. A plug fits into the end of the crankshaft.

Drive Gear Bracket.—After the nut is removed, the drive gear bracket is removed with the puller (Fig. 11). Before removing the drive gear bracket and bearing, be sure that the bevel propeller drive gear has been removed from the end of the cam reduction gear shaft. After the drive gear bracket has been removed, the anchor plate may be dismounted by removing the three retaining screws. If the anchor plate is difficult to remove, it may be broken loose by the use of a padded L-shaped piece of bar stock, applied through one of the lightening holes in the anchor plate.

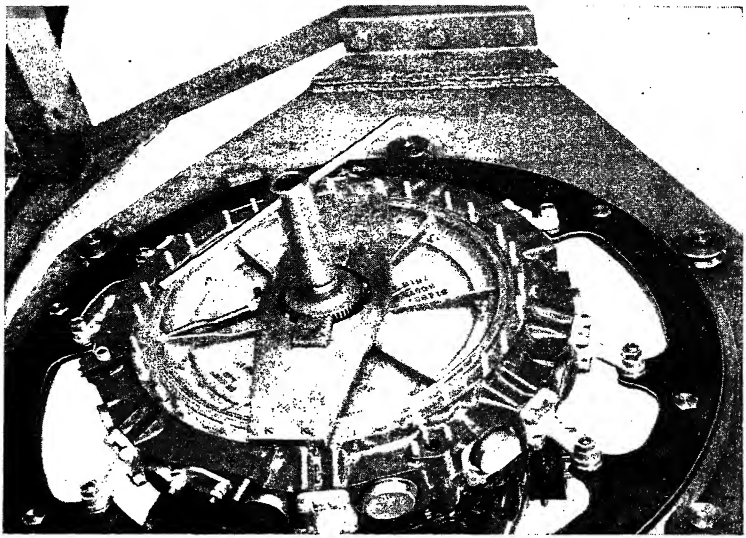


FIG. 7.—Lock to hold accessory drive nut.

Power Section.—The power section is removed from the blower section as a unit (Fig. 6). Remove the oil pressure pipe from the blower section to the power section, and on C type engines, remove the oil scavenge pipe from the power section to the blower section. After the retaining nuts have been removed from the studs between the power and the blower section, the power section may be lifted from the blower section with a chain hoist. Lift vertically until the accessory drive shaft has cleared the bushing in the end of crankshaft.

Next remove the rear section from the intermediate section with the engine horizontal. Remove the magneto drive covers, support the plates and drive shafts, then the starter drive temporary cover plate. A lock (Fig. 7) is used to hold the accessory drive shaft while the starter jaw nut is being loosened. Remove the starter jaw nut, magneto drive gear nuts, gears, and starter jaw. Then remove the tachometer drives and the main oil relief valve with the special tools provided.

Intermediate Rear and Blower Section.—With the engine in the same position, place the lock on the accessory drive shaft adapter on the front of the accessory drive shaft on C-3 engines and remove the nut holding the adapter in place. Remove the adapter with the puller. The accessory drive shaft may then be removed from the cases.

Remove the front and rear impeller bearing cover plates. Attach the special washers to the rear bearing cover plate as the screws are removed. With the lock on the gear of the impeller shaft, remove the nut on the front end of the impeller shaft. The impeller shaft may then be removed from the case with the puller. *The impeller shaft bearings should be scrapped and new bearings installed at each overhaul.*

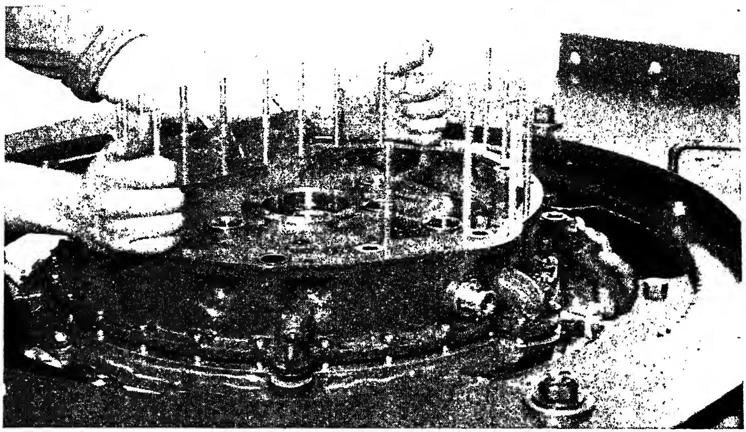


Fig. 8.—Removing intermediate rear section from blower section.

The nuts on the seven through studs which support the diffuser plate and extend through the forward face of the blower section are removed and the engine turned so that the rear of the intermediate rear section faces upward. The nuts on the studs between the two cases are then removed and the intermediate rear section is removed from the blower section (Fig. 8). The impeller is then lifted out of the blower section, the front and rear impeller spacers and bearings removed from the cases, and the blower section removed from the engine stand.

FURTHER DISASSEMBLY

Complete disassembly is urged to allow a rigid inspection of all parts. This prevents serious trouble. In this connection, the parts rack (Fig. 9) and the parts box (Fig. 10) will be found very useful. They are very convenient and prevent damage to parts.

Special tools and wrenches are provided for disassembling and assembling reduction gears of the various ratios. There are also special stands, such as shown in Fig. 11, that make it easier and safer to handle the different parts. Figure 11 also shows the use of the puller for removing the bolts that hold the two sections of crankcase together.

When the retainer has been removed the tappet roller pins are best removed with a magnet, as in Fig. 12. They can however be pushed out from the underside by means of a piece of bent wire if no magnet is available.

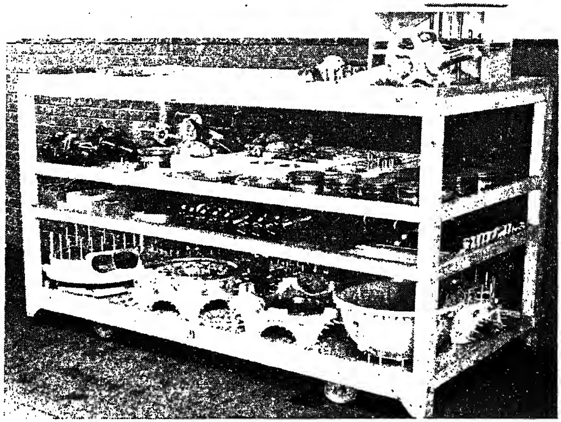


FIG. 9.—This rack is recommended for holding major parts.

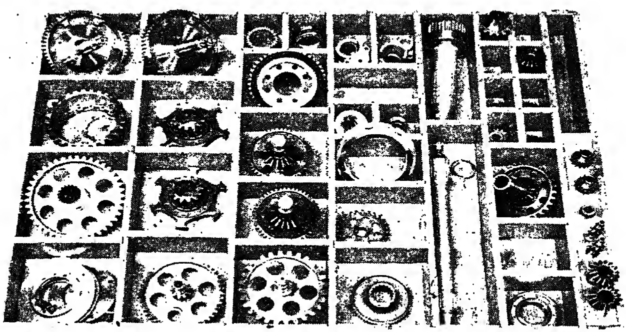


FIG. 10.—Smaller parts are protected in a box, or tray, of this kind.

Another special puller (Fig. 13) removes the rear main bearing inner race. Then take out the oil plug in the rear crankpin. Using two men, remove the master rod assembly and master rod bearing. Remove the center main case over the rear counter weight (Fig. 14). Then the shoes that retain the rollers are jacked apart with three ¼ × 28-in. fine-thread

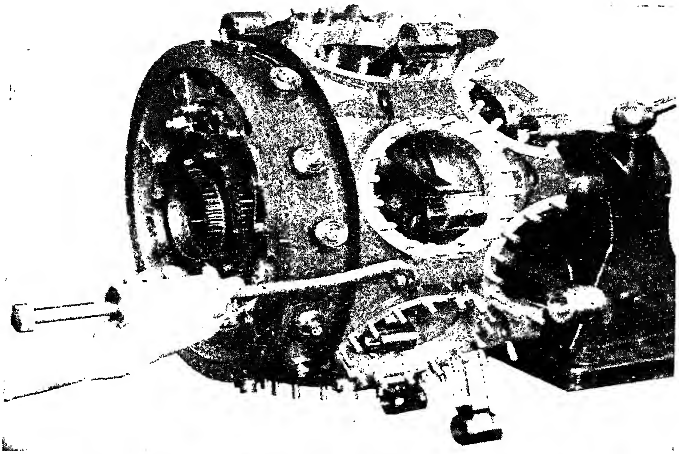


FIG. 11.—Puller for removing bolts. Notice special bench stand for crankcase.

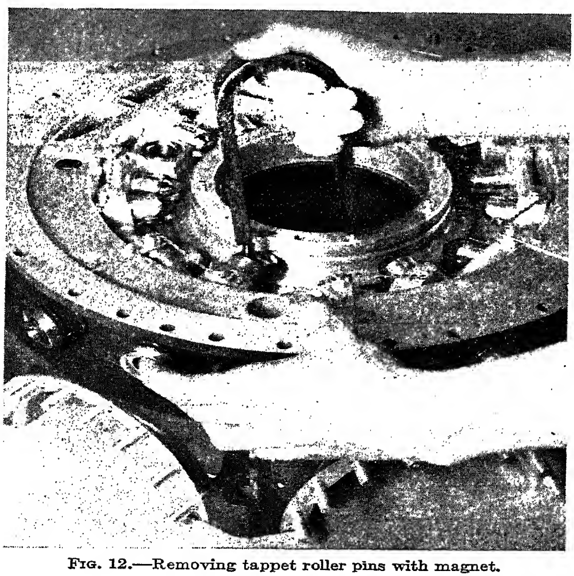


FIG. 12.—Removing tappet roller pins with magnet.

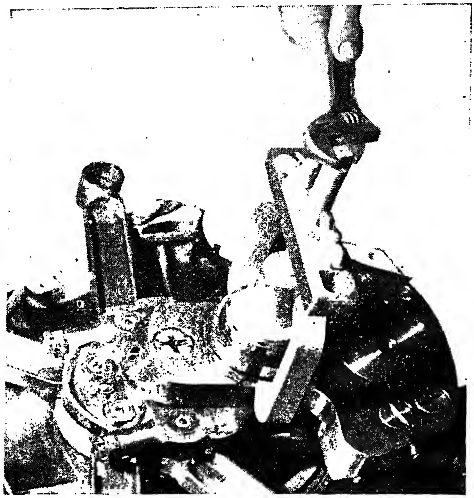


Fig. 13.—Special puller for removing inner race of rear main bearing.

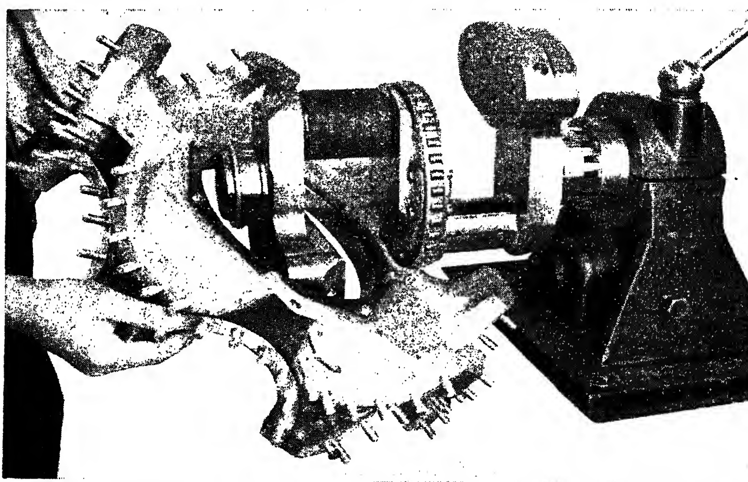


Fig. 14.—Center main case must be "threaded" over the counterweight in this way.

cap screws in holes provided for them (Fig. 15). Pressure must be applied evenly.

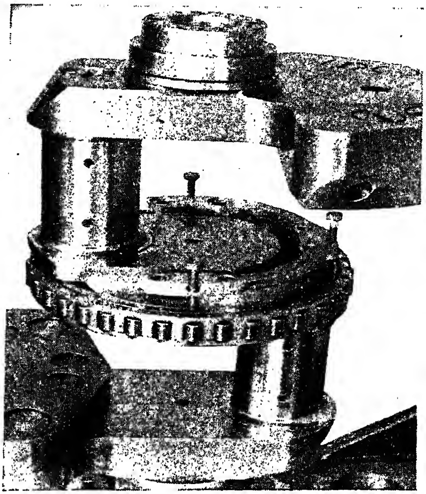


FIG. 15.—Jacking roller retainer shoes apart with cap screws.

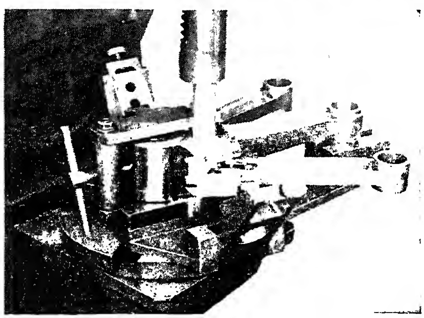


FIG. 16.—Using arbor press to remove knuckle pins.

Knuckle pins, which connect the link rods with the master rod, are larger at the back end and must be pushed *from* the front. Figure 16 shows the fixture used to hold the rod under the press for this operation.

Crankshaft Inspection.—Alignment of the crankshaft can be checked either by mounting in V blocks or between centers, as in Fig. 17. Runout is measured both at the center bearing seat and on a concentric ring placed

over the shaft splines. A runout of 0.002 in. is permissible. *A bent crankshaft cannot be satisfactorily straightened.*

Crank pins wear very little but should be checked for out-of-roundness; the limit is 0.001 in. The surface condition should be noted. See that the oil passages are clear. Check the fit of the bearing seat surfaces on the crankshaft. If the seating surfaces are worn or damaged, they can usually

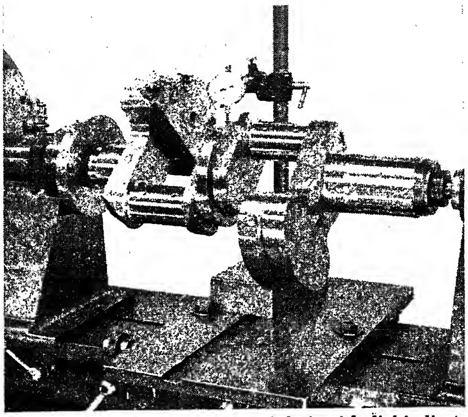


FIG. 17.—Checking runout of crankshaft with dial indicator.

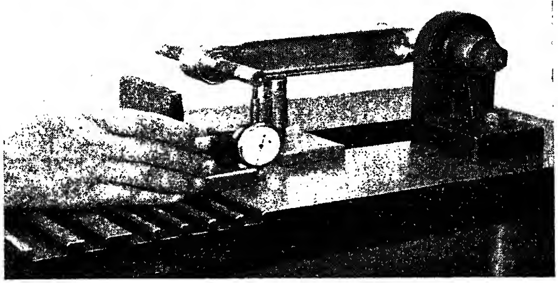


FIG. 18.—Testing a link rod for squareness of the pin holes.

be built up with chromium plate. Bearing retainers should be tin plated at each overhaul.

Knuckle pins intersected by master rod bolts are plated with *silver*, the others with *copper*. If the plating on either is worn, it should be replated. The copper coating is about 0.0001 in. thick. It is usually necessary to renew this at each overhaul.

Connecting Rod.—The master rod bolts should be carefully inspected, especially the threads. These bolts should be replaced after 1,500 hr.

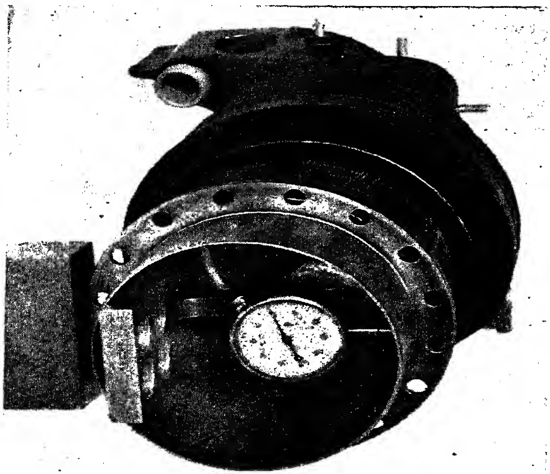


Fig. 19.—Dial gage fixture to check cylinder for out-of-roundne

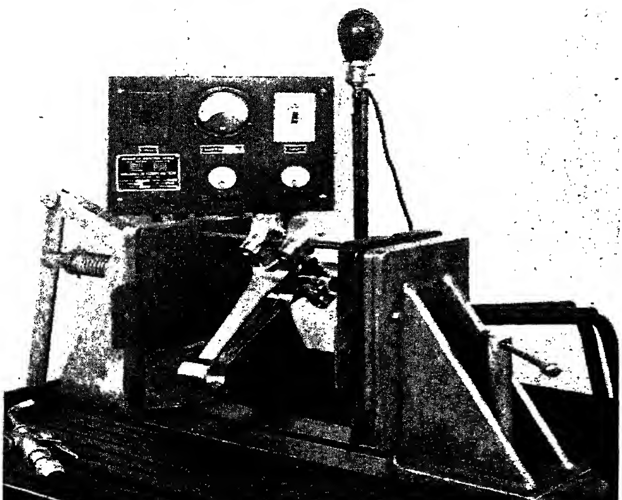


Fig. 20.—Testing mastor rod with magnaflux for cracks.

Bolts used again should be magnafluxed and given a flash coating of tin. Check mating surfaces of rod and cap for galling.

Link rods should be checked for wear and for alignment of holes. Figure 18 shows how squareness is checked. With the rod mounted as shown, the dial indicator shows if the test bar is level.

Pistons and Cylinders.—All piston rings, except the dual oil control rings, are replaced at each overhaul. These may do for two overhauls if tension is satisfactory. Check the piston lands for wear and cracks. A cracked

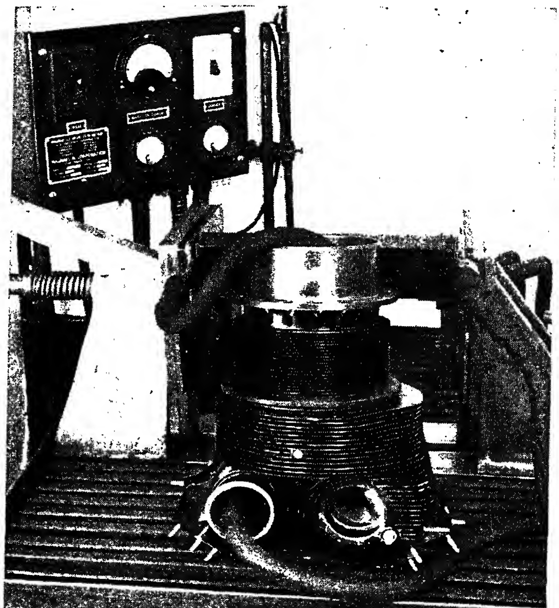


Fig. 21.—Applying current for magnafluxing cylinders.

land will move under pressure. Check the top of the piston for flatness. Reject it if it is depressed 0.008 in. Heating the piston slightly will cause oil to seep out of any cracks.

Check the heavy rib on the front of the cylinder valve housing for cracks, also the heavy flange at the base and the cooling fins. See if the valve seats can be surfaced. Examine the steel liners in the exhaust ports, and the threads on the intake port coupling.

The cylinders are slightly taper, or "choked," to provide a straight barrel at running temperature. Shrinking on the head makes the upper end of the barrel from 0.015 to 0.018 in. smaller than the lower end. This "choke" starts at the shrink band of the cylinder head and extends about 2½ in.

This "choke" makes grinding of the barrel undesirable. In case of excessive wear under 1,500 hr., a new barrel can be installed *at the factory*.

Both nitralloy and chrome-molybdenum barrels are used. Nitrited barrels have "139" stamped on flange; chrome-molybdenum are marked "185."

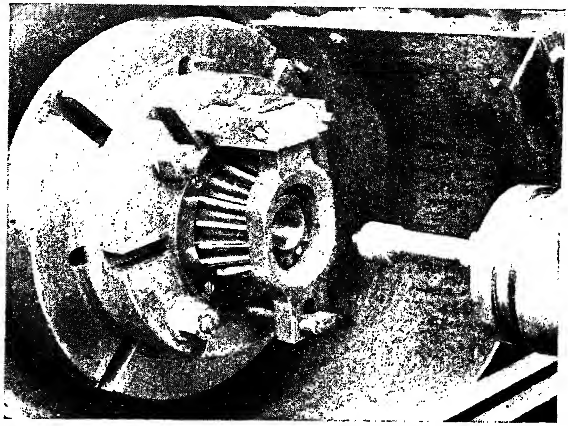


FIG. 22.—Regrinding the bore of a reduction gear.

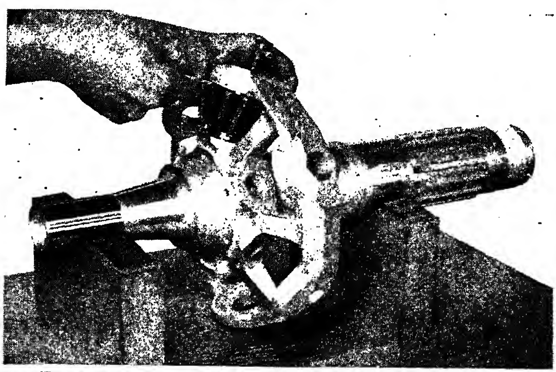


FIG. 23.—Checking end clearance of reduction gear pinion.

Roundness and taper of cylinders are checked by the dial gage fixture (Fig. 19). Out-of-roundness of 0.006 calls for replacement.

Magnaflux Testing for Cracks.—Magnaflux testing magnetizes the part and then covers it with very fine particles of iron. If there is a flaw, the

particles collect on each side and show cracks that the eye cannot detect. This is because one side becomes a north and the other the south pole of a magnet. This method is used on all steel parts of airplanes and engines.

Figure 20 shows a master rod being magnetized; Fig. 21 is a cylinder being magnetized for test. The amount of current necessary varies widely; some parts, such as master rods, need 2,500 amp., master rod bolts only 750 amp. Special apparatus is needed and the parts must be demagnetized before they are used.

Reconditioning Gears.—The bushings in the reduction gearing may need to be replaced. The old ones are forced out and the hole reground, as in Fig. 22. To aid in this a small flat surface is ground at their largest diameter when the bevel gears are made, concentric with the bore. To regrind, the gear is put in a recessed hole of the right diameter and ground to size.

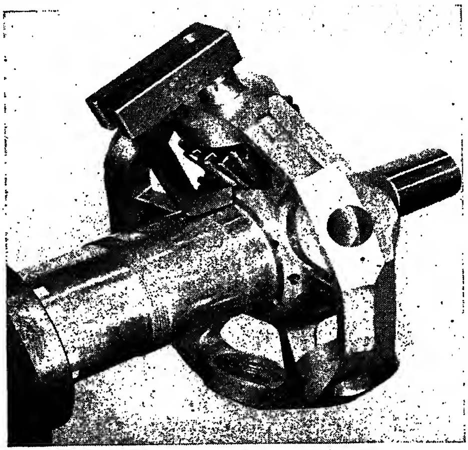


Fig. 24.—Gage for aligning pinion gear.

To aid in mounting the pinions, a "proof spot" is milled on the inside of the outer rim of the pinion cage. Just above, on the beveled surface of the pinion gear bearing race cup, is stamped the exact distance from this proof spot to the center line of the propeller shaft, measured on a line parallel with the pinion shaft (see Fig. 23). Each pinion gear is marked with its correct mounting distance which is etched on the outside face of the gear and is marked "M.D." This is the distance of the outside face of the gear from the center line of the crankshaft, on a line parallel with the axis of the pinion shaft.

The difference between the mounting distance of the pinion gear, as etched on the large face of the gear, and the distance to the proof spot, as stamped on the beveled surface of the bearing cup of the pinion cage, represents the correct or *desired* distance between the proof spot and the top of the pinion gear. The *actual* distance between the proof spot and the top of the pinion gear is measured with a piece of half-round stock of known thickness and a feeler gage. In practice, it has been found that a piece of

half-round stock, ground on the flat side to a thickness of 0.007 in., is suitable. The half-round stock is necessary in order to get a line contact on the curved surface of the proof spot. The *actual* distance should be measured with the pinion gear held out firmly against the thrust bearing.

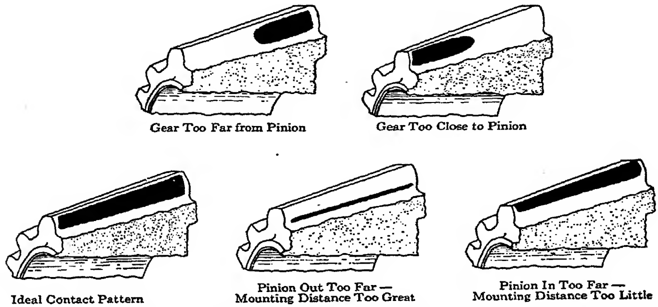


FIG. 25.—Full load contact made by gear teeth with good and bad mountings.

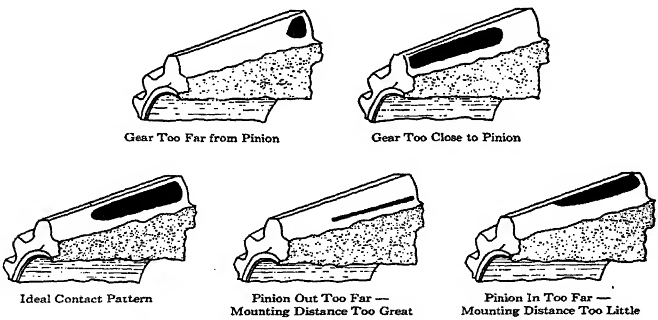


FIG. 26.—Contacts with no load.

The application of this method of fitting the pinion gears is illustrated in the following typical example of a 16-9 pinion gear fitting:

Mounting distance on pinion cage	5.350
Mounting distance on pinion gear	5.275
Desired distance between proof spot and top of pinion	0.075
Thickness of half-round proof rod	0.070
Feeler gage thickness	0.015
Actual distance between proof spot and top of pinion	0.085
Actual distance	0.085
Desired distance	0.075
Computed amount to be ground off bearing spacer	0.010

Note: With the angular thrust type bearings, an allowance of 0.006 in. is made for the natural compression of this type of bearing when the load is applied. The computed amount to be ground off the bearing spacer is reduced by 0.006 in. In the above example, 0.004 in. would be ground off the bearing spacer.

When all the pinion gears have been fitted, the gears are installed in position, each with its individual pinion shaft. The pinion shaft holes in the pinion cage are coated with graphite grease before the pinion shafts are installed. The pinion shafts must be installed so that the locking pin holes are in perfect alignment with the corresponding holes in the pinion cage.

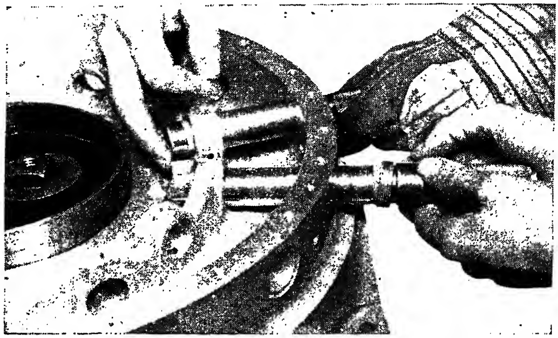


Fig. 27.—Putting new valve tappet guides in place.

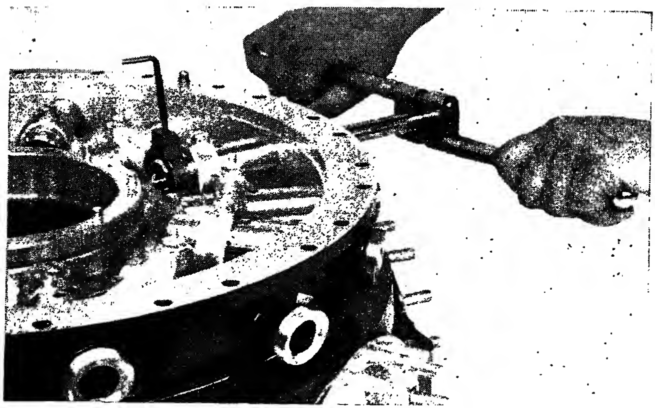


Fig. 28.—Reaming valve guides in place.

An aligning fixture is used for installing these shafts (see Fig. 24). A tapered pin *should not* be employed for making this alignment. If the holes are not in alignment when installed, the shaft should be taken out with the puller. Many times the pinion shaft will turn while being withdrawn and can be drifted back in place in alignment with the holes in the pinion cage.

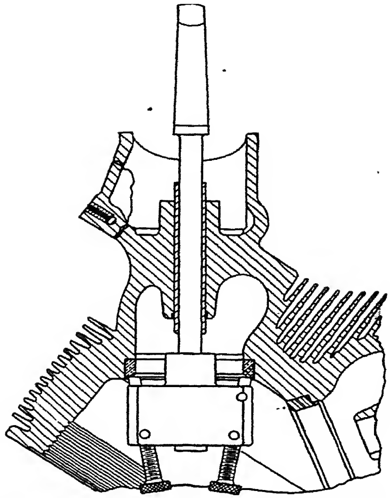


Fig. 29.—Tool for cutting out the old valve seat.

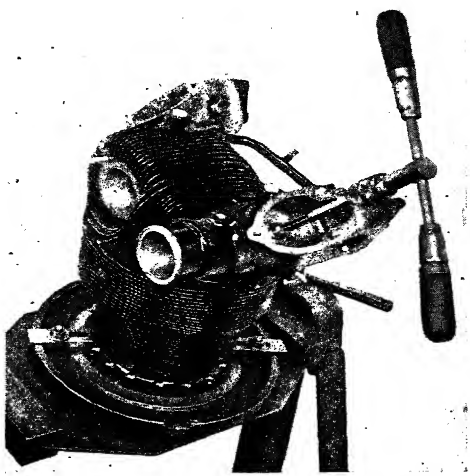


Fig. 30.—Fixture and tools for reaming valve guides in place

Figures 25 and 26 show the contact patterns that are due to different conditions in the meshing of the bevel gears and pinions. This is a good guide in checking the proper alignment and bearing of the gear teeth.

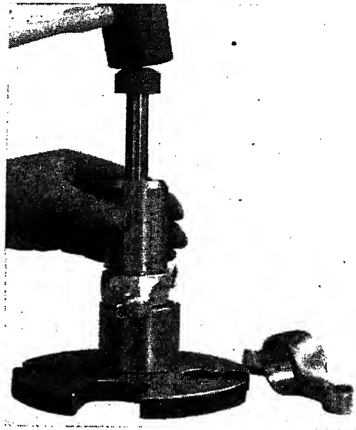


FIG. 31.—A hydraulic tool for removing ball end sockets from rocker arms.

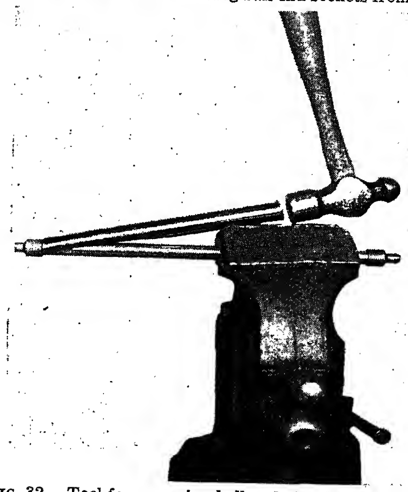


FIG. 32.—Tool for removing ball ends from push rods.

Tappet Guides.—Tappet guides are removed only when necessary to replace them. Heat the metal evenly to 250°F. and pull the guides. This

should be done with the bearing liner nut in place to prevent distortion of the liner. Replacement guides are made 0.005 in. oversize. Heat the case to 300°F. and install new guides, as in Fig. 27. They are reamed as in Fig. 28. Three reamers are used: a rough, straight reamer with pilot; a bottoming straight reamer without pilot; and a helical reamer with pilot. The reaming clamp is also used.

When it is necessary to renew the valve seats, they are cut out by the tool shown in Fig. 29. The tools can be enlarged so that the last cut leaves but a thin shell that is easily removed. To install new seats the cylinder

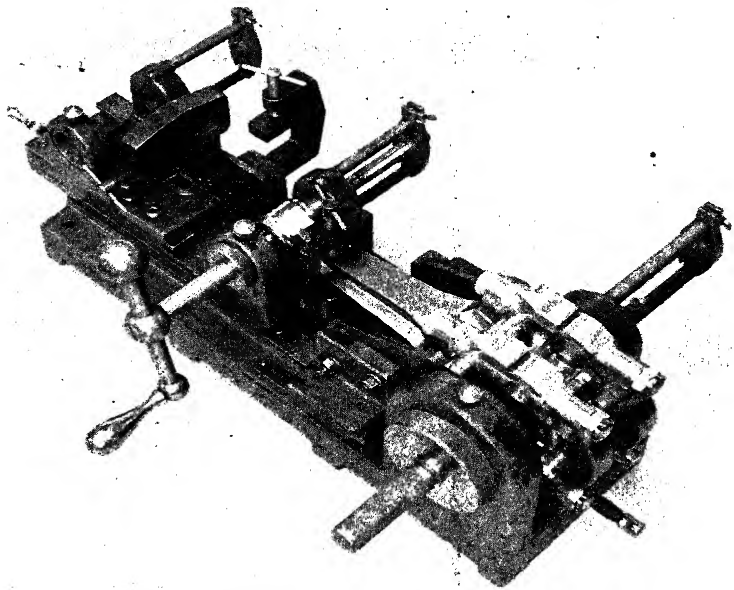


FIG. 33.—A boring fixture for both master and link connecting rods.

is heated carefully to 400°F. If the new seats are chilled with dry ice, it is necessary to heat only to 300°F. New valve guides are reamed, as in Fig. 30.

Ball end sockets are removed from rocker arms by the hydraulic tool shown in Fig. 31. The oil hole in the worn cup is plugged with a tapered steel pin and the rocker arm put in the fixture. With heavy oil in the tool a sharp blow with a heavy hammer forces the socket out, with considerable force. A thick cloth will prevent damage.

Push rod ball ends are removed by holding the rod in a soft-jawed vise and driving the ball off with a tool shaped to fit the rod, as in Fig. 32. The push rod may be lengthened by using a spacer under the ball ends; only one spacer should be used.

A recommended boring fixture for master rods is seen in Fig. 33, which can also be used on the link rods.

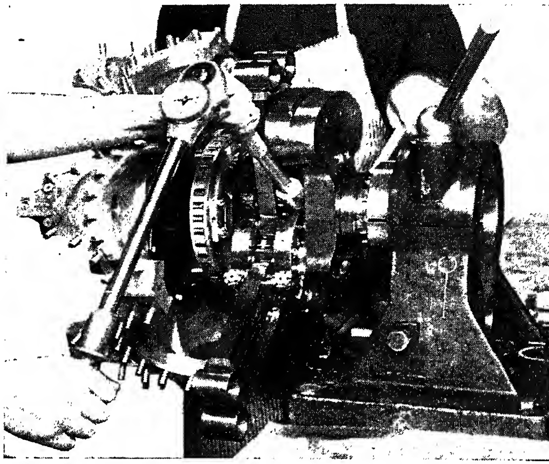


Fig. 34.—Special wrench for tightening nuts on master rods. This shows the torque being applied.

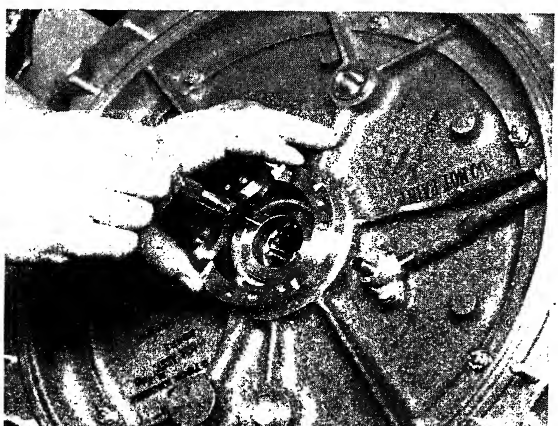


Fig. 35.—Checking the front clearance of the supercharger impeller.

Knuckle pins are put in place in a rod cap and in the master rod by a special fixture. Master rod nuts are tightened with a special wrench

(Fig. 34) that shows the torque being exerted. The proper torque is 1,300 in.-lb. It is best to tighten all bolts to 1,275 lb. and then line up the selected cotter-pin hole. The cotter pins are put in from the crankcase side of the nut and bent over to be tight in the nut.

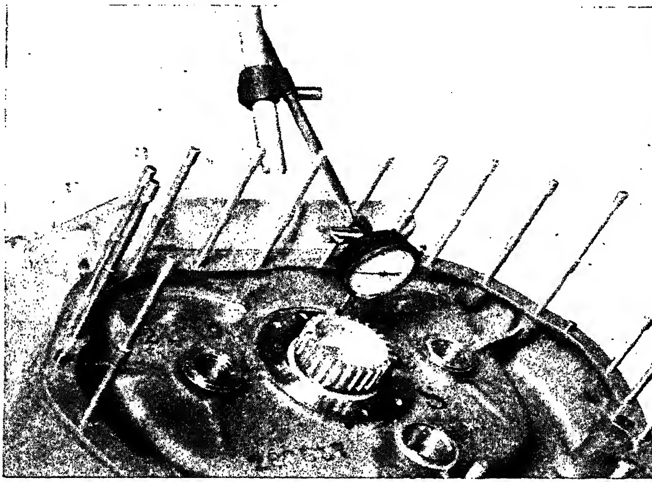


FIG. 36.—Checking rear clearance of supercharger impeller.

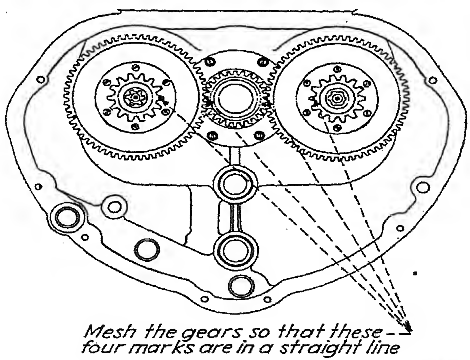


FIG. 37.—Accessory gears must be lined up in this way.

Impeller clearances are important and are checked by micrometer and dial gage. Figure 35 shows the checking of the front clearance, and Fig. 36, the rear. The front clearance should be 0.001 to 0.002 in.; the rear clearance 0.025 to 0.035 in.

The accessory driving gears, shown in Fig. 37, are to be meshed so that the four punch marks are in a straight line, as shown.

ASSEMBLY

Power Section to Blower Section.—Turn the engine stand so that the forward face of the blower section faces upward. Install the rubber sealing ring in the outside groove of the parting surface of the blower section. Suspend the power section assembly with a chain hoist, directly over the blower section. Extreme care should be taken when lowering the power section onto the blower section to see that the two cases are in perfect alignment and that the power section is held vertically. A preliminary trial should be made of the alignment of the cases before attempting the final assembly.

When the proper alignment of the two sections has been made, the power section is carefully raised, the cam reduction gear and spacer installed, and

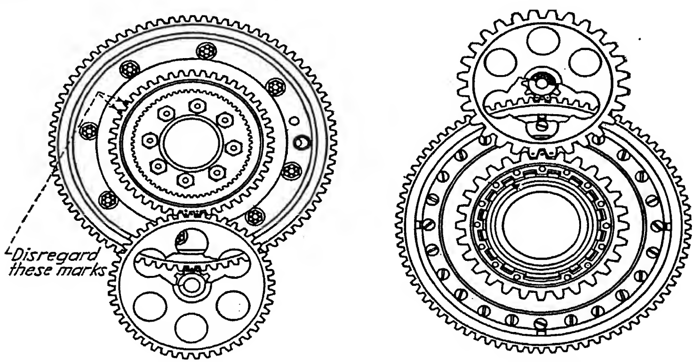


Fig. 38.—Markings on the cam reduction gears.

the rear cam timed to the power section as follows: Cover the rear cam reduction gear spacer with grease and stick it to the face of the cam reduction gear bushing in the rear crankcase. Turn the crankshaft so that the slot between the teeth that have the *double punch marks* faces the center of the cam reduction gear bushing. *Disregard the slot that is marked with the single punch marks* (Fig. 38). Turn the cam so that the tooth with the single punch mark faces the center of the cam reduction gear bushing. *Be sure that the cam reduction gear spacer is still in place.* Install the cam reduction gear so that the marked tooth of the large driven gear meshes with the slot marked on the rear cam drive gear and the marked slot on the small pinion gear meshes with the marked tooth on the rim of the cam. The cam reduction gear may be held in place in the rear crankcase by passing a loop of light twine through the holes in the web of the gear and out through the near-by scavenge oil drain hole in the rear main crankcase. *Check the timing marks on the gears to see that they are in proper alignment.* After making sure that the alignment of the two sections has not been disturbed, lower the power section carefully on the blower section, while the crankshaft

is being rocked back and forth to ensure the meshing of the accessory drive shaft and the internal serrations in the rear cam drive gear. At least three men should be used to lower and steady the power section. If the power section is not held vertical, the accessory drive shaft will not enter the bushing in the rear of the crankshaft and the oil transfer pipe will not enter the rear cam retaining plate. The sections will go together readily if careful attention has been paid to their alignment and the power section is guided in place as it is slowly lowered onto the blower section. When the power section has been lowered into place purely by its own weight, remove the twine that held the cam reduction gear in place and install and tighten the retaining nuts and palnuts.

Install the oil scavenge line and gaskets between the rear section of the crankcase and the blower section on C type engines. After tightening the nuts on the flange studs, tighten, lock and secure the through stud that extends through the scavenge passage on the left-hand side of the blower section.

The valve action of the front bank of cylinders should now be timed, not only to the crankshaft, but also in the proper phase or relation to the timing of the valve action of the rear bank of cylinders. The proper relation between the timing of the two valve actions will exist if the crankshaft is turned approximately 60 deg. in the counterclockwise direction. Put the front cam driving gear in place on the end of the front crankshaft. The single timing mark on the cam drive gear should face the center of the cam reduction gear bushing. If necessary, turn the crankshaft slightly until this condition exists. Turn the cam until the single timing mark on the rim of the cam gear is also facing the center of the cam reduction drive gear (see Fig. 38). Install the cam reduction gear in such a manner that the slots between the marked teeth on the driven gear and on the pinion gear mesh with the marked teeth on the cam drive gear and the gear on the rim of the cam. When the proper meshing of the gears, according to the timing marks, is assured, install the anchor plate and secure it with the three screws. *Do not install the governor drive gear in the end of the cam reduction gear shaft on* C-3 16-9 *geared type engines until the drive gear bracket and bearing or the drive gear bracket and bearing have been installed on the crankshaft.* The outer race of this bearing will damage the governor drive gear if it is in place on C-3 type engines when this bearing is installed.

Install the drive gear and bearing on 3-2 type gearing, or the drive gear bracket and bearing on 16-9 and 2-1 type gearing. Install the bearing on the hub of the drive gear or the drive gear bracket. The bearing should be installed so that the rounded edge of the inner race fits into the rounded fillet of the hub. It is pressed into place with a long sleeve which just fits over the hub and presses on the *inner race* of the bearing. After installation, check with a feeler gage to see that the inner race is seated on the flange of the hub.

Valve Timing.—A check should be made to make sure that the valves are timed correctly to the crankshaft before proceeding with the assembly of the engine. Cylinders 1 and 8 are directly opposite each other on the engine. Since they are on different cranks, which are 180 deg. apart on the crankshaft, these two cylinders fire at the same crankshaft position but on alternate revolutions. If the crankshaft is turned so that it is at the top dead center of the *firing* stroke for either cylinders, that is, with both valves closed, the other cylinder should be in the top dead center of its exhaust stroke (exhaust valve closing and intake valve starting to open). The position of

the valves can be readily checked by noting the position of the tappets in the guides when a light pressure is placed upon them. A final check is made on the valve timing after the cylinders have been installed.

Cylinder Assembly.—The lower or rear bank of cylinders is mounted first, starting with the master rod cylinder in No. 5 position. *The first cylinder mounted on each bank of cylinders should be the master rod cylinder.* The master rod cylinder acts as a guide to prevent the master rod assembly from turning on the crankpin and causing some of the other pistons to be withdrawn from their cylinders until the oil scraper ring expands and locks the piston in that position.

When piston 5 and ring assembly has been thoroughly oiled with regular engine oil, it is assembled to the link rod with the piston pin. The rings are

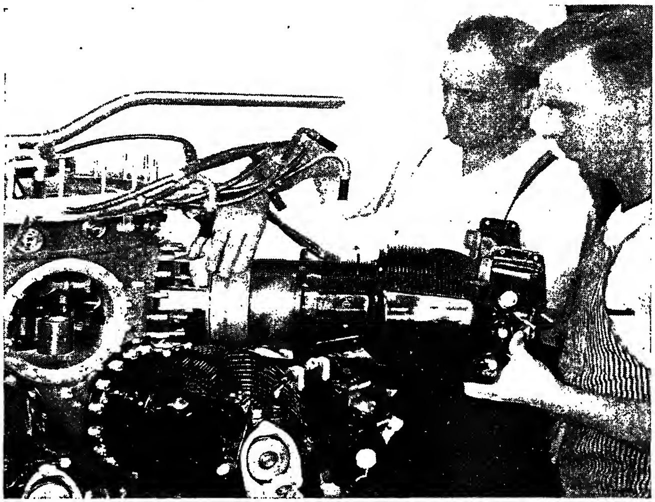


FIG. 39.—Putting cylinders in place on crankcase.

compressed with the ring clamp, the rubber sealing ring placed under the cylinder flange, and cylinder 5 is pushed on over the piston and secured with several nuts (Fig. 39). The remaining cylinders of the rear bank are installed in the same manner, turning the crankshaft a little as each cylinder is mounted so that the link rod protrudes at least half its stroke from the crankcase. The cylinder hold-down nuts are then installed on all the cylinders of the rear bank and tightened. The palnuts are then tightened.

On the C-3 engine a spherical faced washer is placed in the similarly shaped counterbore in the flange of the cylinder before the nuts are mounted. The correct torque of the tightening of the cylinder hold-down nuts is 300 in.-lb. On engines having spherical washers under the hold-down nuts, the washers should be centered as well as possible and all nuts should be tightened evenly before the final tightening. Avoid pulling the stud off to one side while tightening the nuts.

Before the front row of cylinders is installed, the high-pressure oil line from the blower section to the front main crankcase and the scavenge oil line from the reduction gear housing are placed in position and secured temporarily with twine so that they may be moved aside to facilitate the tightening of the remaining cylinder studs. On the C type engine, the scavenge oil line extends to the oil outlet connection. On C-3 engines, it extends to the forward face of the blower section. The ignition manifold is then put in place and secured with the studs and mounting pedestals. The individual spark-plug leads are all tied together to keep them out of the way while the front bank of cylinders is being assembled. The cylinders of the front bank are then mounted, starting with the master rod cylinder in position 12.

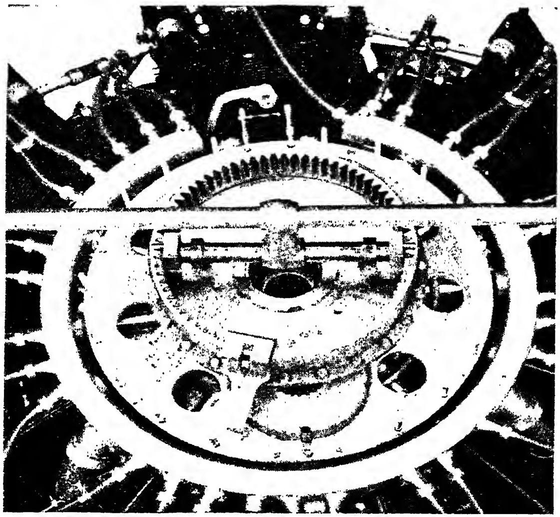


FIG. 40.—Using the timing pointer.

When all the cylinders have been mounted in their proper positions, the hold-down nuts are tightened and secured with palnuts.

Valve Timing—Final Check.—To make sure that no error has been made in the assembly of the gears of the valve mechanism, it is necessary to check the valve timing. The inlet valve should open 20 deg. before top dead center and the exhaust valve should close 20 deg. after top dead center. This condition is checked on both cylinders 1 and 8, thereby checking the timing of both the front and rear valve cams.

With piston 1 in the exact top dead center position on the compression stroke, adjust the valve clearance of both the inlet and exhaust valves so that they have 0.060 in. clearance underneath the valve adjusting screw. Place the timing pointer (Fig. 40) on the rim of the large drive gear so that its center lines up with the timing mark, etched on the outer rim. Turn the crankshaft in a *counterclockwise* direction until the finger of the timing

pointer is in alignment with the inlet open mark 20 deg. before top dead center.

The outer edge of the anchor plate is stamped "I.O. 20°." At this point, the inlet valve should just be starting to open. This can be checked by putting a 0.0015-in. feeler gage under the valve adjusting screw and noting the point at which it tightens up. When this position has been checked, the crankshaft is turned in the *counterclockwise* direction until the timing pointer is in alignment with the exhaust close mark. This is 20 deg. after top dead center and is marked "E.C. 20°." At this point, the exhaust valve should just be closed. This may be checked by inserting a 0.0015-in. feeler gage under the valve adjusting screw and noting the point at which it is released. Owing to the manufacturing tolerances in the full floating cam bearing, these points will not always coincide exactly with the markings on the anchor plate. The inlet valve usually appears to open early, and the exhaust valve to close later than the specified marking. A variation of ¾ in. in this respect is not considered excessive.

After cylinder 1 has been checked and the rear cam found to be correctly timed, the same procedure is repeated on cylinder 8 to check the timing of the front cam.

Push Rods and Intake Pipes.—After the timing of the valves has been checked, the push rods and intake pipes are assembled on the engine. The number and position of the push rods are etched on one end of the rod. For example, exhaust valve 1 is marked "1. EX." The rods should be assembled in their proper position with the numbered ends facing the center of the engine. When the push rods are installed, a check should be made to see that there is no interference between the top of the tappets and the steel inserts in the push rod cover tubes.

The push rod cover tubes are installed with the flanged end toward the center of the engine. Care should be taken to see that each end of the cover tube contains its packing and gasket in the packing gland nut. The push rods are installed by turning the engine until the piston is at the top dead center on the compression stroke and by depressing the rocker arm with the rocker arm depressor. The push rods may then be put in place. The packing nuts on the inner end of the cover tubes should be tightened first. If the nuts on the outer end of the tube are tightened first, the flanged inner end is liable to be damaged. The packing nuts on the push rod cover tubes are tightened and secured with safety wire.

The intake pipes are then assembled to the engine. Care should be taken to see that the packing is in place on the blower end of the intake pipe and the packing and rubber sealing ring on the valve head end. The rubber sealing ring should be next to the flange end. When installing the pipe, it is good procedure to put the packing ring on the pipe and then insert the pipe in the blower section rather than put the ring in the recess in the blower section before the pipe is put in place. Tighten the packing glands evenly. Secure with safety wire. During the installation of the intake pipe, a thin steel scale, placed across the face of the intake pipe coupling on the cylinder, will allow the upper flange of the intake pipe to slide across the face of the coupling without damage to the coupling threads. Once the pipe is in place, it may be drawn to the rear and the scale removed.

Valve Adjustment.—Both the exhaust and intake valves are adjusted to a clearance of 0.010 in. under the valve adjusting screw. Turn the engine in a counterclockwise direction until piston 1 is in the top dead center position on the compression stroke. Insert a 0.010-in. feeler gage between the

ball tip of the adjusting screw and the top of the valve. Unlock the locking nut on the valve adjusting screw and adjust the screw until there is just 0.010-in. clearance at this point. Lock the adjusting screw lock nut. This nut should be made hand tight. Do not strike the wrench with any object while locking this nut. Tools for performing this work are supplied in the engine tool kit accompanying each engine. After tightening the lock nut, the clearance of the valve should again be checked.

When the valve clearances of cylinder 1 have been adjusted, those of the remaining cylinders are adjusted in a similar manner, following the firing sequence of the engine. The firing sequence of the Twin Wasp engine is 1-10-5-14-9-4-13-8-3-12-7-2-11-6. It is particularly important that the cylinders are set at the exact top dead center of their compression stroke when the valve clearances are set or checked.

After all the valves have been adjusted, the engine is turned two complete revolutions and the clearances are again checked. Any valve clearance that is less than the specified amount should be readjusted to the original 0.010 in. Any clearance that is found to be more than 0.010 in. in the new position is disregarded and the original adjustment is retained.

Magneto Mounting. *Magnetos with Removable Drive Gears.*—When magnetos are mounted on an engine, the engine should be in cylinder 1 firing position for the type of magneto being mounted. This will be either 20 deg. for magnetos having 4- and 8-lobe breaker cams, or 29.4 deg. for magnetos having 14-lobe compensated breaker cams.

Place the proper timing pointer on the driving gear so that the timing mark on the pointer lines up with the timing mark on the rim of the gear. Turn the engine in a *counterclockwise* direction until the pointer is at the timing mark on the anchor plate on the *firing stroke* of cylinder 1 (see Fig. 41). When the 8-lobe breaker cam magneto is on the engine, use the 20-deg. timing mark. With the 14-lobe breaker cam magneto use the 29.4-deg. timing mark.

Turn the drive gear of the magneto until the timing mark on the distributor is in alignment with the timing mark on the distributor housing and a scale or straightedge placed across the flat step on the breaker end of the breaker shaft is in alignment with the two marks on the rim of the breaker housing.

Hold the magneto in this position with the fingers on the distributor and the magneto oil seal in place and mount it on the engine. The magneto should mount with the holding studs in the approximate center of the adjusting slot. If the magneto will not mount in this position, remove the gear from the end of the drive shaft of the magneto and remount it in another position. This gear fits on a hexagonal shaft and will mount in six positions. After this has been done, repeat the procedure of mounting the magneto on the engine. One of the six positions of the magneto gear will allow the magneto to mount on the engine with the mounting bolts in the middle of the adjusting slots.

When both magnetos have been mounted, tighten up the holding nuts just enough to hold the magnetos flat up against their mounting faces but loose enough so that they may be rotated in their adjusting slots for the accurate timing of the engine.

Magnetos with Fixed Drive Gears.—Place the timing pointer on the large drive gear so that it lines up with the timing mark on the rim of the gear, and rotate the engine in the *counterclockwise* direction until the timing pointer is at the 20-deg timing mark before top dead center on the firing

stroke on cylinder 1 for 4-lobe cam magnetos and 29.6 deg. for 14-lobe cam magnetos.

Turn the drive gear of the magneto until the timing mark on the distributor is in alignment with the timing mark on the finger of the distributor case and a scale, or straightedge, placed across the flat spot on the end of the breaker cam is in alignment with the two marks on the rim of the breaker housing.

With the magneto held in this position with the fingers on the distributor and the magneto oil seal in place, mount it on the engine. The magneto should mount with the holding studs in the approximate center of the adjusting slot. If the magneto will not mount in this position with the timing marks lined up, as described above, within very close limits, turn the drive gear of the magneto until the distributor segment has rotated twice. At this time, the flat spot on the breaker will be in alignment with the two marks on the rim of the breaker housing. In this magneto position, there is a new spline relationship between the magneto and the engine. If the magneto will not mount readily in this position, turn the engine over two complete revolutions in the counterclockwise direction and try to mount the magneto in the two positions, as described above. If the magneto will not mount readily in either of its two positions in the second crankshaft position, turn the crankshaft twice more and repeat the trials. There are four crankshaft positions in which a different spline relationship exists on the magneto drive and two positions of the magneto in which its timing marks are in alignment and in which it has a different spline position in relation to the engine. This combination makes eight different possibilities of mounting a magneto so that the retaining studs are near the center of the adjusting slots. At least two of these positions should allow the magnetos to be mounted without difficulty.

Although each magneto is mounted on the engine separately without regard as to whether the other magneto will mount in that particular crankshaft position, the trials for the mounting of the two magnetos may be carried on simultaneously.

When both magnetos have been mounted, the nuts on the retaining studs are tightened just enough to hold the magneto flat up against its mounting face but loose enough so that it may be rotated in the adjusting slots for the accurate timing of the engine.

Magneto Timing.—In timing and synchronizing magnetos to engines, occasions will arise where two distinct methods are employed. The first method is used when the reduction gearing is removed at overhaul; the second when an engine is installed in an airplane and the magneto timing is accomplished with the reduction gearing assembled on the engine.

Overhaul Method.—When timing magnetos at overhaul with the reduction gearing removed, the position of piston 1 on its compression stroke is located through the top center mark on the reduction drive gear which is lined up with the specified advance mark on the anchor plate.

Owing to a condition which is inherent in all radial engines of conventional master rod design, the travel of each piston, with the exception of the master rod pistons, is a few degrees either early or late in relation to the crankpin. The master rod pistons register top center position at a zero crank angle. On Twin Wasp engines, piston 1 is 4.4 deg. in advance of the crankpin. This point should be borne in mind and should be given due consideration when timing an engine.

There are two types of magnetos in use on Twin Wasp engines: one has either four or eight equally spaced breaker cam lobes and the other has fourteen cam lobes, so spaced as to compensate for the normal irregular angular position of each link rod in respect to the master rod. This latter type of magneto ensures each cylinder's firing with its position at the desired advance position. The former type does not compensate for this condition and consequently each cylinder fires at a slightly different advance position. Therefore, when timing magnetos at cylinder 1, each type requires a different marking on the engine anchor plate.

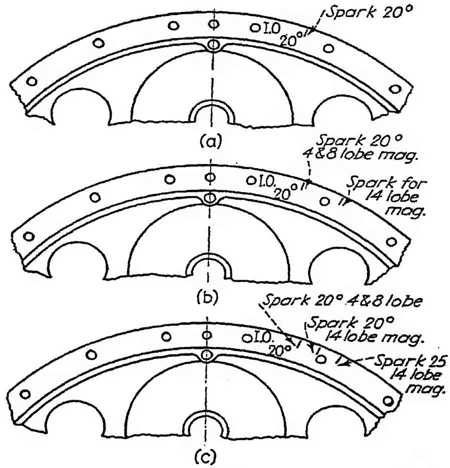


FIG. 41.—Marks for setting magnetos in timing the engine.

The markings, as shown on *a* in Fig. 41, were used on engines having four- or eight-lobe cams and the top center mark on the reduction drive gear is lined up with the 20-deg. spark advance when piston 1 is on its compression stroke.

With the introduction of the 14-lobe compensated magneto, the markings, as shown on *b*, were incorporated on the anchor plate. The 20-deg. spark advance is used for magnetos having 4- and 8-lobe cams and the mark located to the right is used for 14-lobe compensated magnetos. This mark, although not indicated as such, is actually 29.4 deg., or the equivalent of 25 deg. spark advance for piston 1.

The present arrangement, as shown in *c*, has marks for both types of magneto breaker cams. It will be noted that the first 20-deg. mark is actually 20 deg. and is used to line up top center mark on the reduction drive gear for 4- and 8-lobe cams, which actually sets piston 1 15.6 deg. before top center in piston travel. The second 20-deg. mark is actually 24.4 deg. and is used for positioning the top center mark on the reduction drive gear when using 14-lobe magnetos. By setting the crankpin at 24.4 deg., piston 1 is 20-deg. before top center, and, therefore, when cylinder 1 is firing 20 deg. early, all remaining cylinders will fire likewise due to the compensated cam. The next mark of 25 deg. is actually 29.4 deg. and is used for the 14-lobe magnetos on engines which it is desired to time at a 25-deg. spark advance.

To make it possible to interchange the two different types of magnetos on engines in the field, it is recommended that at the next overhaul all anchor plates on engines, not marked in accordance with *c*, in Fig. 41, be marked accordingly.

Field Method.—Setting engines for timing magnetos with the reduction gearing installed is different from the overhaul method. The position of

piston 1 is located by means of a top centering device whereas in the overhaul method, it is located through the crankshaft by means of the markings which have been described. When piston 1 is located at top center, the propeller shaft is turned back in a clockwise direction the number of degrees proportional to the desired spark advance, this depending on the reduction gear ratio. The current propeller ratios are 3 to 2, 2 to 1, or 16 to 9, and the number of degrees the propeller shaft should be turned is $\frac{2}{3}$, $\frac{1}{2}$, or $\frac{9}{16}$, respectively, of the specified advance which can be found on the data plate of each engine.

When using 4- or 8-lobe magnetos on an engine having a spark advance of 20 deg., piston 1 should be set at 15.6 deg. Therefore, this position may be found through the reduction gearing by turning the propeller shaft $\frac{2}{3}$, $\frac{1}{2}$, or $\frac{9}{16}$ of 15.6 deg., which is 10.4 deg., 7.8 deg. or 8.8 deg., respectively.

When using 14-lobe magnetos, piston 1 is set at 20 or 25 deg., depending on the spark advance specified and there is no need to compensate for the 4.4 deg. Therefore, the propeller should be turned the number of degrees proportional to the specified advance.

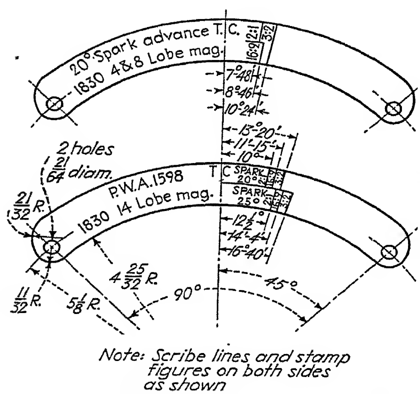


FIG. 42.—Template recommended for use in setting pistons for timing.

To provide a simple and easy means of setting piston 1 the correct number of degrees in piston travel before top center, it is recommended that a template be used, as shown in Fig. 42. This can be mounted on the reduction gear housing and secured in place by two cap screws. After piston 1 has been positioned at top center, a piece of stiff wire may be fastened to the propeller shaft, or the propeller hub, and lined up with the top center mark on the template. Then by turning the propeller shaft in a *clockwise* direction approximately 90 deg. and then returning in a counterclockwise direction until the wire attached to the propeller shaft, or propeller hub, lines up with desired mark on the template, piston 1 will be at the desired position.

Timing Procedure.—When the top dead center position for cylinder 1 has been determined and the timing pointer on the crankshaft, or propeller shaft, has been set to coincide with the top dead center mark on the anchor plate or the timing template, the engine is turned approximately 90 deg. in a clockwise direction and two strips of feeler gage stock, 0.0015 in. thick, are inserted between the breaker points of the magneto. Care should be taken to open the breaker points just enough to insert the feeler strips. The engine is then rotated in a *counterclockwise* direction until the timing pointer coincides exactly with the proper timing mark for the engine, magneto, and gearing combination.

When the timing pointer is set exactly on the desired timing mark, the nuts on the retaining studs of the magneto mounting flanges are loosened a little and the magnetos rotated until the feeler strips are released when a

slight tension is placed on them. The magnetos are then tightened and a check made to see that they are in synchronism. The engine is turned in a *clockwise* direction until the timing strips tighten in the breaker contacts and the engine is then turned slowly in a counterclockwise direction until the feeler strips are released. The feeler strips should be released at the same time, with the same tension, when the timing pointer registers with the proper timing mark.

Checking Contact Breaker Adjustment.—Turn the engine until the timing mark on the distributor is in alignment with the timing mark on the distributor housing and a scale, or straightedge, placed on the flat step on the breaker cam is in alignment with the two marks on the breaker housing. In this position the breaker contacts should be just opening to fire cylinder 1.

Scintilla pivotless type breakers should always be adjusted so that the contacts open at the proper position of the cam and not for any fixed clearance between contacts. This method of adjustment is different from that employed on the lever type breakers.

If the straightedge, which has been placed on the flat step of the breaker cam, is more than $\frac{1}{32}$ in. (0.79 mm.) out of alignment with the markings on the breaker housing, the breaker should be adjusted so that the contacts open just as the straightedge is in alignment with the marks. To make this adjustment, hold the cam in a position to open the contacts as indicated by the straightedge, loosen the two locking screws in the plate that holds the breaker in place, and adjust the opening of the breaker contacts with the eccentric adjusting screw.

After the adjustment has been made, tighten the two locking screws. If a feeler gage, 0.0015 in. (0.038 mm.) thick, is placed between the contacts and a slight tension placed upon it, the opening of the contacts can be determined by the release of the feeler strip. **Caution.** When opening the breaker contacts, either for inspection or to insert the feeler strips, it is imperative that the main spring is not raised more than $\frac{1}{16}$ in. (1.6 mm.). Further opening will weaken the main spring.

Replacement of Distributor Blocks.—Particular care should be taken when the distributor blocks are removed and replaced to see that the carbon brush in the center of the distributor block is not broken. At both removal and replacement, the two screws that keep the wire manifold elbow from turning and the knurled connection should be loosened to ensure the maximum amount of slack and flexibility. To remove, the cover screws are loosened and the block moved vertically a short distance until it is possible to tilt the blocks backward and keep the carbon brush away from the edge of the front case of the magneto. In replacing, the block is tilted backward and inserted in the magneto until the carbon brush has cleared the forward case of the magneto. Care should be taken to see that the insulation of the ignition wires is not damaged while the knurled connection is loose.

Wiring.—The numbers on the distributor blocks show the serial firing order of the engine.

Observe that each magneto is wired so that No. 1 on the distributor block goes to No. 1, or first cylinder, in the firing order of the engine, and No. 2 on the distributor block goes to the second cylinder in the firing order of the engine which is No. 10. No. 3 on the distributor block goes to the third cylinder in the firing order of the engine, which is No. 5, etc., until all cylinders have been wired in their proper firing order. The firing order of the Twin Wasp engine is 1-10-5-14-9-4-13-8-3-12-7-2-11-6. The

right magneto fires the front spark plugs of each bank of cylinders and the left magneto fires the rear spark plugs.

RUN-IN OF ENGINES AFTER OVERHAUL

After an engine has been overhauled, it is essential that it be properly run in before it is placed in service. The purpose of this run-in is to seat piston rings and to burnish whatever new parts may have been installed, such as bearings, pistons, etc., and, at the same time, to ensure that the engine is running satisfactorily. The measurement of fuel and oil consumption and the observation of the engine's performance with a standard test propeller, as compared with that of a new engine under the same conditions, are the principal checking factors.

Test Stands.—It is desirable that the engine be run in on an enclosed test stand, although, in an emergency, it may be run in while mounted in an airplane. This, however, does not permit close control of the engine temperatures, the fuel and oil consumption, or an accurate determination of the engine's performance. An enclosed test stand is advantageous not only from the standpoint of quietness and convenience but also because it gives protection to the workmen mounting and dismounting the engine and is of distinct advantage, in cold climates, for ready engine starting and engine temperature control.

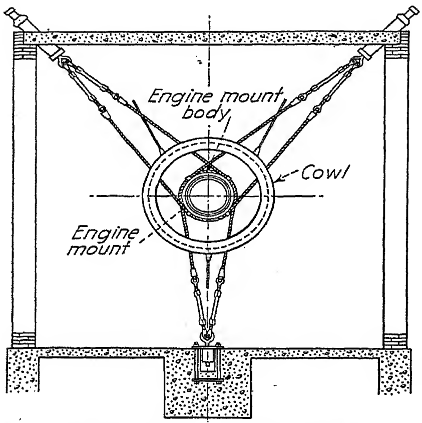


FIG. 43.—Suspension mounting for engine test stand. This is a Canadian design.

There are several important factors that should be considered in the design of a test stand. The area under the roof and between the walls should be ample to provide at least a 3-ft. propeller tip clearance, and the area of the air inlet and exhaust stacks should be at least two-thirds of the cross-sectional area of the test house at the propeller. The interior of the test house should be as free as possible from obstructions that will interrupt or deflect the propeller air blast. Obstructions that will interrupt or deflect the propeller air blast usually cause eddying and surging and result in a rough running engine.

Severe rigidity of the test-stand structure should be avoided. Its construction should simulate, as nearly as possible, the flexibility inherent in the average airplane structure. In this connection, the suspended type of test stand, such as will be discussed later in this section, has been found to be very advantageous.

Torque stands are not recommended for overhaul test equipment in view of the necessity of continual calibration and because the measurement of the actual horsepower output is not essential. It is also difficult and expensive to construct a torque stand that is entirely free from excess rigidity.

The entire assembly of engine mount and supporting drum is suspended by means of four loops of stranded steel cable, two at each end of the drum. Each loop is anchored in rubber blocks in the corners of the roof and side walls. The anchoring of the engine mount assembly is effected by two loops of similar cable, one at each end of the drum. These loops are also rubber mounted and secured to anchor bolts in the floor, directly under the assembly. Turnbuckles are provided in each loop of cable so that the proper tension for the desired rigidity may be obtained. In order to hold the engine mount assembly against the propeller thrust, the two supporting cable loops on each side of the test stand are crossed; that is, the loops from the rear of the supporting drum are anchored at the front of the test house and the loop from the front of the supporting drum is anchored at the rear of the test house. This arrangement is illustrated in Fig. 43. This is a Canadian design.

The engine mount assembly is constructed in two parts: the engine mount proper and the supporting drum. The supporting drum consists of a hollow steel cylinder, 6 ft. long and 30 in. in diameter, constructed on ¼-in. steel. The ends of the cylinder are closed with ⅜-in. flanged plates. The engine mount is constructed of a flat steel mounting plate and welded tubing, as shown in Fig. 43. This construction permits a rugged engine mount and also the maximum of accessibility to the accessory section of the engine.

Test Clubs.—From the viewpoint of convenience, economy, and cooling efficiency, a four-bladed wooden club propeller is recommended for the average testing stand. Since the location and characteristics of different types of test houses affect the propeller characteristics, it is necessary to calibrate a new test club on the stand with which it is to be used. Test clubs are supplied slightly oversize on the diameter so that the blade tips can be cut down to allow the engine to turn its rated r.p.m. at manifold pressure under approximately standard conditions for the given location. The rated r.p.m. and manifold pressure may be obtained from the performance curve of the engine. A new propeller should be calibrated on a new engine, or on one that is known to be running satisfactorily, and the work should be carried out on a day that is considered average for the location. After the tips of the propeller have been cut to the desired diameter, the test club should be properly balanced.

Cooling Shrouds.—During the testing of an engine, a shroud should be used to ensure satisfactory cooling of the cylinders. The cooling shroud takes the place of the cowling on a normal engine installation. It is usually flared at the forward edge so as to deflect sufficient air over and between the cylinders. It should be constructed of a heavy-gage durable material to withstand the constant buffeting of the test propeller and should be mounted independently of the engine so that it may be quickly moved to the front of the test stand to allow easy access in mounting and dismounting the engine.

Engine Room.—The cross section of the engine room should not be less than 16 ft., but a minimum over-all test house length of 38 ft. is permissible if lack of space dictates. In the latter case, vertical intake and exhaust stacks should be 16 ft. wide by 11½ ft. deep and 22½ ft. high and the engine will be centrally located in the 15 ft. length of the engine room, proper. The horizontal part, alone, without the vertical extension, may be used if noise is not an important factor and soundproofing is unnecessary. An additional 30 ft. of length would be necessary for soundproofing. It is of

course assumed that nothing to restrict or disturb a smooth flow of air will be in close proximity to the horizontal stack opening.

The horizontal intake stack is preferable to the vertical stack because it provides a smooth flow of air over the engine. However, if space permits mounting the engine 20 ft. from the inner edge of a 16-ft. square vertical stack, the effect of the horizontal stack will be approximated. The minimum dimensions which have been stated should be considered only when it is necessary to adapt an existing building and an effort should be made at least to approach the greater dimensions.

The engine room may be either square or round in cross section, bearing in mind the 16-ft. cross-sectional dimension, or it may be round only at the central portion which envelopes the engine and propeller. If the latter type of construction is used, the transition from the square to the round section should be gradual, and shaped to ensure a smooth flow of air over the engine. The advantage of a cylindrical-shaped engine room is that it contributes to smooth air flow. A disadvantage is that a specially constructed stand is necessary for working around the engine.

Rolling steel doors should be provided at both ends of the engine room so that the room will be weather-tight when not in use.

Whether or not the engine room is soundproofed depends entirely upon the locality in which it is constructed. In any event, it is good policy to investigate the possibility of soundproofing requirements at a future date and to make the necessary provisions for the incorporation of soundproofing with minimum structural changes.

The entire structure may be built of brick and mortar, or reinforced concrete. Inasmuch as the supporting cables are designed for a maximum tension of approximately 80,000 lb., the wall and roof structure should be capable of withstanding this stress with an adequate safety factor.

Layouts and detail construction drawings of recommended test houses are available and may be obtained from the Pratt and Whitney Service Department.

Controls.—Engine controls are provided by suitable bell cranks and torque tubes which extend from the engine mount assembly to the operating room. It is recommended that the streamlined member which houses the operating controls, fuel lines, oil lines, and instrument wires extend from the side of the engine mount drum to the wall of the test house on a level with the center line of the supporting drum.

This streamlined member should be supported from the wall of the engine room and should be connected to the supporting drum by a flexible leather section. Flexible connections should be provided at this point in the fuel lines, oil lines, and engine controls. The use of a trench or pit underneath the engine is not recommended. In case of any leakage or breakage of the fuel line, fuel will collect in such a trench and any explosion or fire will be conducted directly to the control room.

Preheater.—A preheater, utilizing the heat of two exhaust stacks, or a steam radiator should be provided in order to supply the engine with preheated air between a temperature range of 140 to 212°F. under all climatic conditions. Such a preheater should be constructed large enough so that there is no appreciable reduction in the air pressure at the carburetor.

Fire Precautions.—In the construction of the engine test stand and engine room, particular attention should be paid to any factors that might contribute to the fire hazard. It has been found particularly advantageous in this regard to eliminate the trench in the floor of the engine room. All

similar depressions that might gather excess fuel or vapor should be avoided. Likewise, there should be no passageway or vent by which any fire can enter the control room. It is advisable to build a permanent CO_2 installation in the engine mount and to install the control valve where it will be readily available to the operator. In addition to this permanent system, a portable system, such as Foamite or Pyrene, should be provided.

General.—The suspended type of construction has proved to be the most practical from the viewpoint of initial cost, maintenance, and operation of the engine. Not only is the stand free to move in all directions, due to the rubber mounting, but the degree of flexibility or rigidity can be adjusted by means of the turnbuckles in the cables to suit large or small engines. Especially noteworthy in this type of construction is the freedom of the stand to rotate about its major axis.

Mounting Engine on Stand.—Using the lifting sling, place the engine in position on the mounting plate of the stand by means of the hoist and secure with eight bolts. All bolts should be securely fastened before the sling is removed from the engine. The usual precautions for alignment should be observed as when mounting the engine in an airplane.

The following instrument connections, controls, oil and fuel lines, and exhaust and inlet systems should be connected:

1. The manometer line to measure manifold pressure should be connected either to the blower section or an inlet port.
2. Connect the tachometer.
3. Connect the throttle and mixture controls.
4. Connect the oil inlet and outlet pipes.
5. Install the oil inlet thermometer connection.
6. Connect the oil pressure gage line. (Connect to the right-hand side of the blower section.)
7. When carburetors having pressure-actuated economizers are used, connect the pressure line from the blower section to the carburetor.
8. Connect the fuel line to the pump and to the carburetor.
9. Connect the fuel relief valve line into the fuel inlet line.
10. Connect the fuel pump drain line.
11. Connect the priming system.
12. Connect the fuel pressure gage line to the carburetor.
13. Connect the head thermocouples to at least two, preferably four, cylinders.
14. Install the air scoop or duct together with the heater control.
15. Connect the air inlet thermometer line.

Test Procedure.—Before starting the engine, the wobble pump in the oil intake system should be operated with the oil intake line disconnected at the engine, until a supply of warm oil reaches the engine. This precaution is particularly important in cold weather. The oil intake line is then connected to the engine and the engine turned over at least one dozen times by hand in the counterclockwise direction, to make sure that there is no oil in the lower cylinders.

After the engine has been started, it should be warmed up at least 15 min. at approximately 800 to 1,000 r.p.m. Before proceeding with the test proper, the oil inlet temperature should have reached at least 140°F. (60°C.). During the warm-up period, the operation of the thermostatic oil control in the rear section should be observed. This should maintain an initial starting pressure of at least 200 lb. per sq. in. until the temperature of the oil has reached 100°F. (38°C.).

On the C type engine, the low-pressure relief valve should be adjusted to prevent excessively high oil pressure when the engine is run with cold oil. Connect a pressure gage to the low-pressure oil connection which is found on the exact center of the lower surface of the rear section, directly underneath the generator flange. Adjust the low-pressure oil relief valve so that a pressure of 23 lb. per sq. in. is maintained at 2,300 r.p.m. at 158°F. (70°C.) oil inlet temperature.

The high-pressure oil relief valve on both the C and the C-3 engines should be adjusted to maintain 85 to 100 lb. per sq.in. above 1,500 r.p.m. after the oil temperature has reached its desired operating range of 140 to 167°F. (60 to 65°C.).

The fuel pressure should be adjusted to suit the type of carburetor being used. On the float type carburetor, the fuel pressure should be adjusted to maintain 4 to 5 lb. per sq.in. On the injection type carburetor, the fuel relief valve should be adjusted to maintain 14 to 16 lb. per sq.in. (15 lb. desired) at the carburetor.

Warning.—It has been found that, in test stand operations where the oil is vented to the outside air, there is a tendency for the oil to form a high acid content. This condition, if allowed to remain unchecked, can cause corrosion or "washing" of the leaded master rod bearing and possible destruction of the bearing. It is particularly important that a close check be kept upon the acid content of the oil. It is good practice to change the oil every 30 hr. and, every second oil change, or every 60 hr., to flush the oil system out with a petroleum solvent. When this is done, the oil cooler should be removed and cleaned separately. If, at any time, the neutralization number of the oil at the end of the test exceeds 0.65, the engine should be disassembled and the master rod bearings inspected.

The following schedule outlines the minimum run-in period recommended for the polishing of newly installed bushings and piston rings of an overhauled engine.

Engines Rated at 2,500

R.p.m.	Min.
Warm-up	15
1,000	120
1,500	60
1,750	60
2,000	60
2,250	120
2,400	30
2,550	15

While the engine is being run in, the mixture control should be in the full rich position with the NA-C12D2 type carburetor. When the PD12B series carburetor is used, the engine may be run in with the mixture control in the automatic rich position, if satisfactory cylinder cooling can be maintained.

After the engine has been run in, the fuel consumption should be checked. It is recommended that the fuel consumption be measured at rated power and speed and at several points within the cruising range of the engine. When a float type carburetor is used, it is desirable to have a master carburetor available so that, in cases of abnormal fuel consumption, the fuel consumption of the engine may be rechecked at the same speeds as with the original carburetor. Such comparative tests should be made on the same day so as to ensure identical climatic conditions.

When the injection type carburetor is used, its characteristics are determined on the carburetor test bench after the carburetor has been overhauled.

However, it is advisable to make an additional check on the fuel consumption when the carburetor is mounted on the engine on the test stand. When using the NA-C12D2 carburetor, measure the fuel consumption at rated power with the mixture control in the full rich position and also measure the fuel consumption at several different engine speeds within the cruising range. When using a carburetor of the PD12B series, measure the fuel consumption at rated power with the mixture control lever in the full rich and automatic rich positions; also measure the fuel consumption at several speeds within the cruising range with the mixture control lever in the automatic rich and automatic lean positions.

At the conclusion of the other tests, a check should be made on the oil consumption within the cruising speed range of the engine. The oil consumption test indicates whether or not the newly fitted piston rings have become well seated. In the event that the oil consumption is abnormally high, it is sometimes possible to correct the condition by running the engine for 2 hr. additional at approximately 1,600 r.p.m. in order further to seat the piston rings. If the condition is not corrected within this time, cylinders should be removed and the condition of the rings investigated.

The test club propeller does not have the same flywheel effect as an airplane propeller. It is therefore impractical to make a final idle adjustment of the carburetor on the test stand. However, at the completion of the test, the engine should be checked for idling, for acceleration, and for operation of the magnetos. The engine should not lose over 100 r.p.m. when operating on one magneto at 90 per cent rated speed. If the engine is to be placed in storage, it should be run at least 30 min. on *unleaded gasoline* before being removed from the run-in stand.

A log of the engine test should be kept and filed with the engine inspection and overhaul records.

SECTION III

ROLLS-ROYCE MERLIN AERO ENGINE, SERIES II

This is a supercharged, geared, liquid-cooled engine with 12 cylinders in two banks of 6 each, at a 60-deg. angle, with each block as a single unit (Fig. 1). The cylinders are 5.4 × 6 in. The international power rating is 990 at 2,600 r.p.m. at 12,250 ft.; the take-off power is 890 and maximum 1,030 hp. The maximum diving r.p.m. is 3,600. The compression ratio is 6 to 1; the propeller reduction is 0.477 to 1; the weight is 1,335 lb. The cylinder banks are numbered "A" and "B" instead of "R" and "L"; A is right hand, B is left hand.

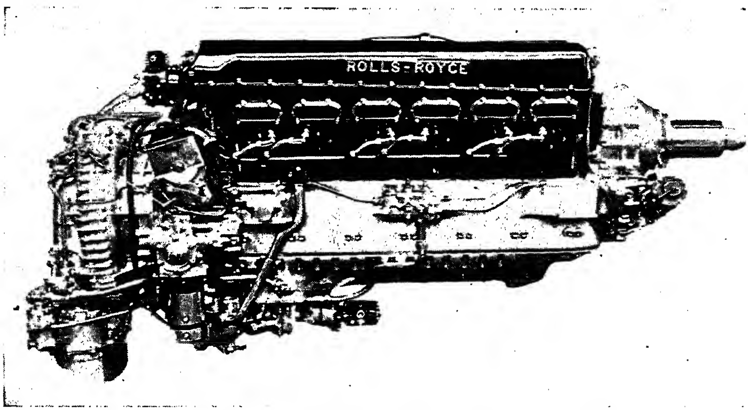


Fig. 1.—Right side of Rolls-Royce Merlin Aero Engine, Series II.

There are two magnetos, two spark plugs per cylinder, and the fully advanced magneto timing is 45 deg. before the top dead center. The contact breaker gap is 0.012 in.; spark-plug gap, 0.012 to 0.015 in. The firing order is 1A-6B-4A-3B-2A-5B-6A-1B-3A-4B-5A-2B.

The valve tappet clearance for timing is 0.020 in. The inlet valve opens 31 deg. *before top* dead center and closes 52 deg. *after bottom* dead center; the exhaust valve opens 72 deg. *before bottom* dead center and closes 12½ deg. *after top* dead center.

The coolant is ethylene glycol, the same as for the Allison engine. A hand starting gear and a 12-volt motor are provided.

The cylinder block is aluminum with steel liners that fit at the upper end to form both a liquid and a combustion joint. A floating gland forms the joint at the bottom. Inclined shafts from the crankcase drive camshafts in

each cylinder head. The six-throw crankshaft has seven bearings and drives all the auxiliaries through a thin spring-steel shaft that gives torsional flexibility. The connecting rods are of the forked type; the pistons are aluminum with floating bushing and piston pins.

A geared pressure oil pump supplies lubrication and two other geared pumps drain the crankcase at each end, maintaining a dry sump. The

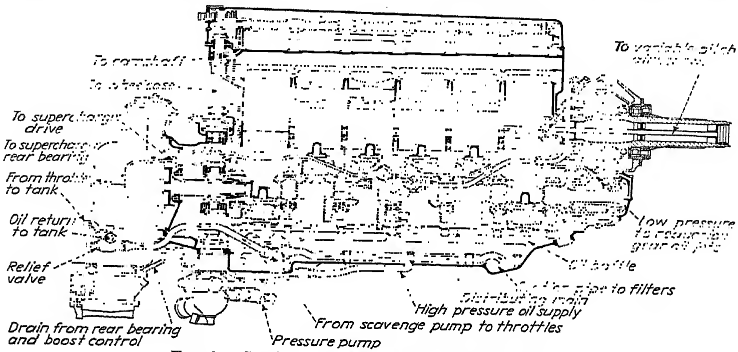


FIG. 2.—Section through one bank of cylinders.

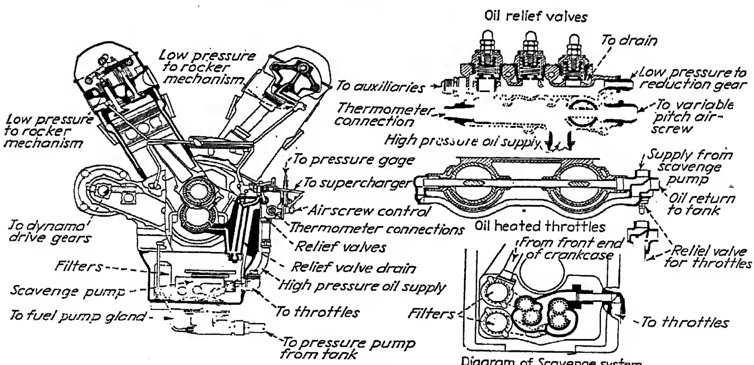


FIG. 3.—Cross section of engine and other details.

lubrication system is shown in Figs. 2 and 3. The first-stage oil pressure carries 150 lb. to provide for propeller operation; the second stage, from 60 to 70 lb., supplies main high-pressure oil to the bearings. Drilled oil passages carry oil through the crankcase to a main pipe that supplies each of the seven main bearings through two holes in the lower half of the bearing. From here the oil goes through the crank webs to the crankpins, through holes in bearings 2, 3, 5, and 6. Nos. 2 and 6 have annular grooves and 3 and 5 have part annular grooves that register with holes in the crankshaft bearings to

provide uniform oil distribution. The fuel pump bushings and gland are also fed from the high-pressure system through a restricting hole in the pump.

A third oil stage carries 4 to 8 lb. pressure for the various auxiliaries such as camshaft, rockers reduction gear, electric generator, supercharger drive

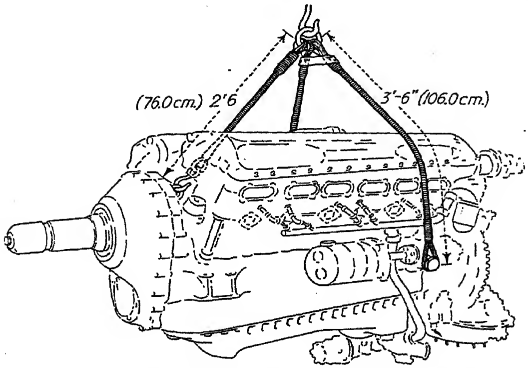


FIG. 4.—Sling used in handling engine in and out of plane.

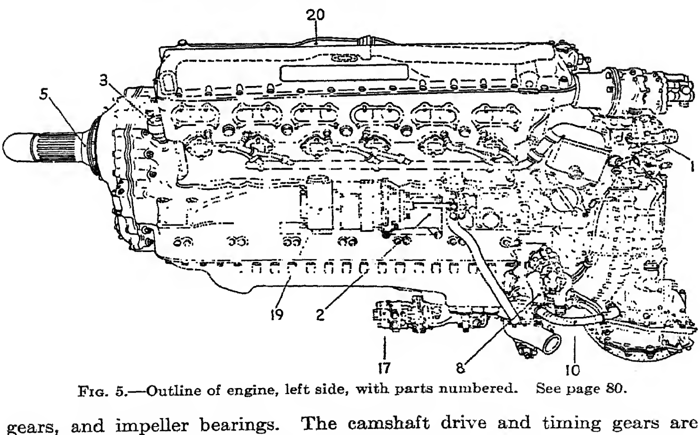


FIG. 5.—Outline of engine, left side, with parts numbered. See page 80.

gears, and impeller bearings. The camshaft drive and timing gears are lubricated by oil draining back to the crankcase.

The pistons and small ends of the connecting rods are splash lubricated, a baffle in the lower crankcase preventing an excess of oil from reaching the cylinder walls. The hot scavenged oil is returned through the carburetor hollow throttle valves and spindles. A safety valve prevents the pressure

exceeding 25 to 30 lb. Gauze filters in the suction side of each scavenge pump are easily removed for cleaning.

Handling the Engine.—Three points are provided for attaching slings, as in Fig. 4, which also shows the length of each cable. Two of the slings have eyes; the short sling has a hook. Slings should be padded where they contact the cylinders.

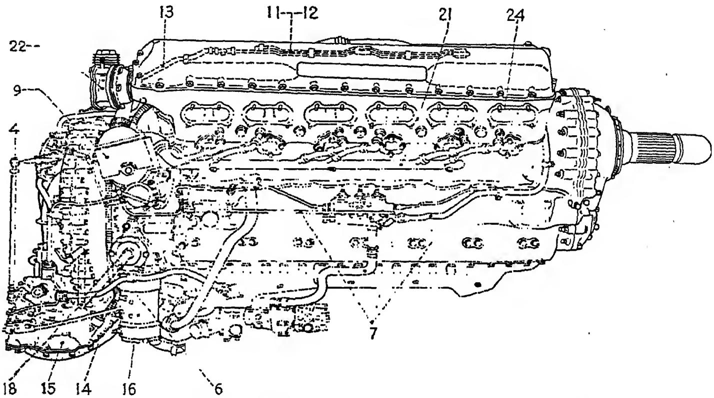


FIG. 6.—Outline of right side of engines. See list of parts in text.

Figures 5 and 6 show the engine in outline and give some of the main parts, as follows:

1. Automatic boost regulator
2. Bracket for electric generator
3. Crankcase breather
4. Mixture control, coupled to pilot's lever
5. Split taper collet, for propeller hub
6. Starter motor coupling and splined drive
7. Main pressure oil pipe and variable pitch propeller controls
8. Duplex fuel pumps
9. Magnetos
10. Fuel supply pipe to carburetor

11–12. Fuel priming and drain pipes on induction manifolds

13. "Petroflex" main priming pipe
14. "Superflexit" main drain pipe
15. Gauze screen for carburetor air intake
16. Starter motor
17. Lockheed hydraulic pump
18. Hand starter gear
19. Electric generator
20. Main coolant outlet pipes
21. Ignition wiring
22. Air compressor, piston type
24. Ignition or spark plugs

Cooling System.—The coolant, ethylene glycol, is circulated by a centrifugal pump to each cylinder block and head, then through two main

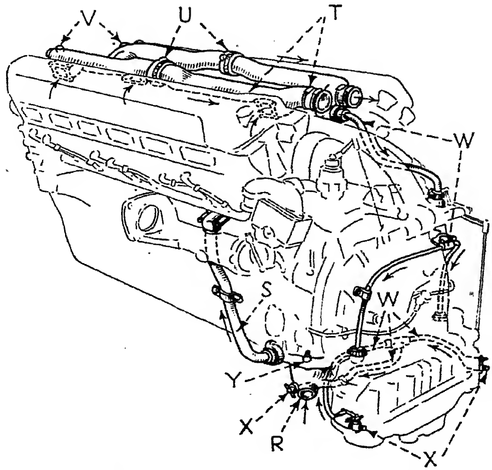


FIG. 7.—Cooling system of engine with parts named below.

R = Return to pump from radiator
S = Pump delivery to cylinders
T = Main outlet pipes to tank
U = Gland joints
V = Vent plugs for releasing air when filling
W = Auxiliary pipes for carburetor heating
X = Drain cocks
Y = Pump lubricator

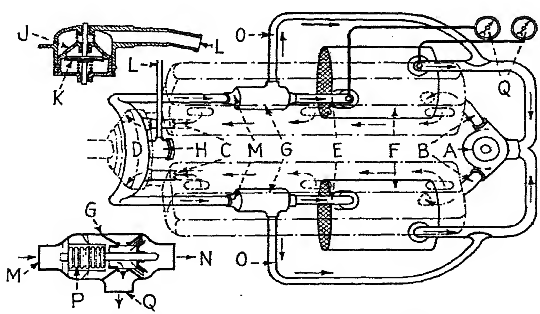


FIG. 8.—Diagram of cooling system with names of parts.

A = Glycol circulating pump
B = Pump delivery to cylinders
C = Return from cylinders
D = Header tank
E = Connection to radiator
F = Radiator
G = Thermostat
H = Double-acting relief valve
J = Detail of outlet valve } *H*
K = Detail of inlet valve } *H*
L = Vent
M = Inlet to thermostat
N = Outlet from thermostat (hot)
O = By-pass to pump (cold)
P = Thermostat bellows (capsule)
Q = Temperature meters (inlet and outlet)

outlet pipes which discharge into a header tank; it then goes to a radiator below and returns to a single inlet connection to the pump. Figures 7 and 8 show these connections.

Dismantling the Engine for Overhaul.—As with all engines, a stand, or cradle, should be used that will permit the engine to be turned so that it may be either upright or upside down, and with either bank of cylinders vertical. The sequence recommended for dismantling is to separate into the following units:

Reduction gear
Magnetos
Controls
Ignition wires, inlet side
Supercharger, carburetor, and boost control
Ignition wires, exhaust side
Air compressor or auxiliary drives from camshaft
Rocker covers and camshafts
Camshaft drive casings
Cylinder blocks
Pistons
Supercharger drive gear and spring drive
Wheelcase and pumps
Lower crankcase and oil pumps
Crankshaft and connecting rods

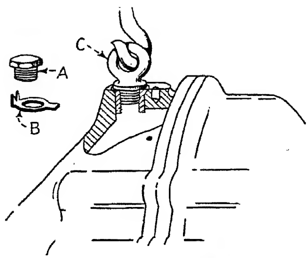


FIG. 9.—Screw eye for lifting reduction gear case.

A screw eye is provided for lifting off the reduction gear case after the screw *A* (Fig. 9) is removed. The hollow flanged dowels that locate the gear case and crankcase are removed with the extractor shown in Fig. 10. If these pullers are not available, great care must be taken to part the cases in perfect parallel to avoid damage.

The supercharger can be removed easily by attaching the lifter seen in Fig. 11. This is attached to the case by the knurled screws shown.

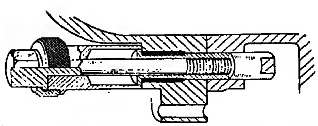


FIG. 10.—Hollow flanged dowel that locates gear and crankcases.

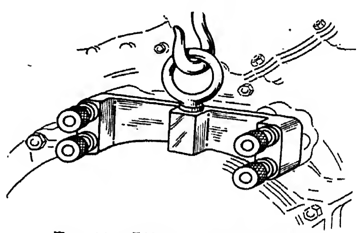


FIG. 11.—Lifter for supercharger.

Fourteen cap nuts hold the cylinder blocks to the crankcase. Start from the center and work toward the ends in removing these; *do not remove the side covers or slack the six clamp nuts.* The cylinder blocks are lifted with the plate and eye (Fig. 12) and mounted on the rig in Fig. 13 which holds it as it was on the crankcase. Bearing caps are removed by the lifter in Fig. 14; the end bars fasten to the bearing bolts and the screw in the center fits into a thread in the center of the bearing cap. The hook in Fig. 15 lifts the crankshaft out of the bearings.

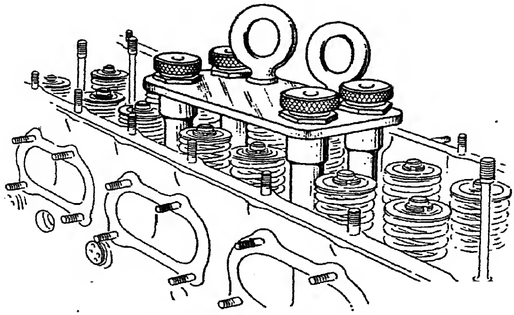


FIG. 12.—Plate and eyes for lifting cylinder blocks.

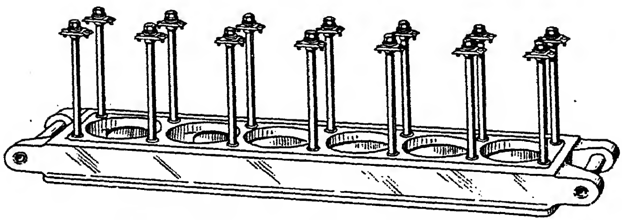


FIG. 13.—Fixture for holding cylinder blocks.

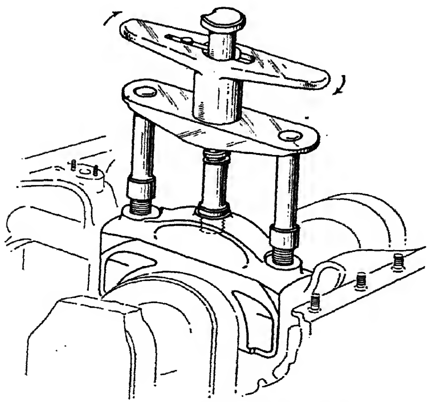


FIG. 14.—Lifter for bearing caps.

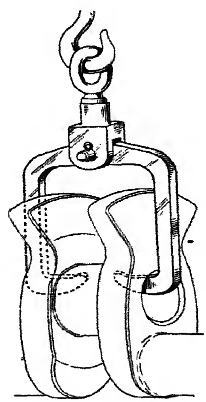


FIG. 15.—Hook for lifting crankshaft out of bearings.

THE SUPERCHARGER

The supercharger is a high-speed centrifugal blower driven through gearing from the rear of the engine as seen in Fig. 16. The gear ratio is 8.588 to 1, which gives the impeller a speed of 22,330 r.p.m. when the engine is at the normal speed of 2,600 r.p.m. These are three systems of planet gears, driven by friction from a pinion on the crankshaft by means of a slipper held in contact with the inside of the gear wheel rim by light springs.

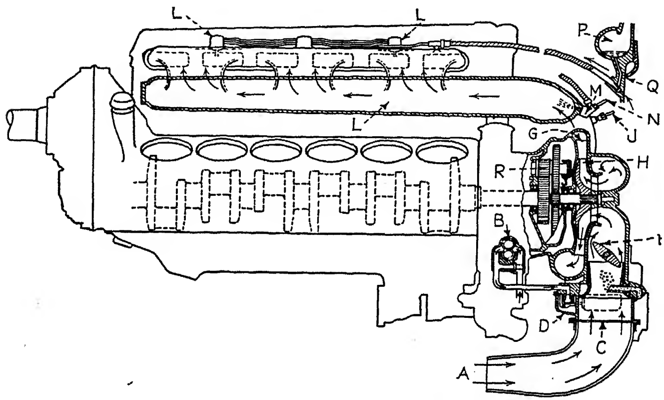


Fig. 16.—Construction of supercharger.

A = Air intake to carburetors
B = Fuel pump and relief valve
C = Filter gauze
D = Carburetors
F = Throttle valve
G = Supercharger vane deflector ring
H = Supercharger rotor
J = Boost gage connection.
L = Main distribution manifold
M = Priming and volute drain discharge nozzles
N = Main supply pipe from priming pump
P = Supercharger volute
Q = Carburetor intake
R = Balanced slipper gear for supercharger drive

At high speeds the centrifugal force greatly increases the radial pressure and drives the impeller at the desired speed. The friction drive equalizes the loading of the gear teeth and protects the gearing against damage due to sudden variations of crankshaft speed. The main parts of the supercharger are shown and named in Fig. 16. Its construction is shown in Fig. 17 and the permissible tolerances are given in Table 1. End location and thrust are controlled by the single ball bearing; the washer *C*, between the gear and the inner ball race, adjusts the endwise motion.

Careful inspection of this unit is very important as small cracks may develop in the impeller blades, oil thrower ring, or ball bearing. These should be tested with magnaflux or with chalk.

The supercharger gearing is shown in Fig. 18 and the permissible wear is given in Table 2.

End location and thrust of the impeller are provided for by this ball bearing which is positioned endwise by its housing and outer race.

The gear shaft itself is adjusted endwise by a washer *C* placed between the gear and ball inner race, the steel thrower ring being placed at the rear end.

The inspection of this assembly is particularly important, and the permissible dimensions must be strictly adhered to. Gear teeth should also be subjected to careful scrutiny for "running hot" or "picking up."

Should a component part of the impeller assembly be renewed, the whole assembly should be rebalanced on knife edges to within the limit weight used at the works (0.0625 oz.).

The large diffuser ring should not be interchanged with that from another engine, as it is carefully fitted initially to obtain the correct "nip" when the two casings are bolted together.

Parts should be reassembled in a similar relative order, ensuring that all nuts are locked as when originally assembled.

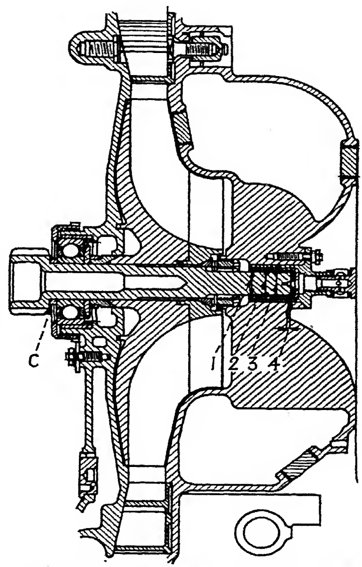


FIG. 17.—Section of supercharger. See fits and clearances in Table 1.

Supercharger Drive Gears and Spring Drive.—The supercharger unit, timing gears, and all auxiliary components are driven from the crankshaft through a torsionally flexible shaft which provides a spring drive. Twisting of this shaft is positively limited and torsional oscillations are damped by the supercharger rotor friction drive as described later. The spring drive unit smooths out irregularities in angular velocity and torque in the drive between the crankshaft and auxiliary components.

For the purpose of providing resilient means of driving the rear auxiliary units so that torsional oscillations may be reduced, a long, comparatively thin, shaft is used, serrated at each end and made of spring steel. In the event of fracture, however, a main outer shaft is brought into action, the serrations on its drive bushing normally having a rotational clearance with those in the crankshaft bushing rear end.

Serrations at each end of the inner drive shaft engage the crankshaft bushing and supercharger gear wheel at the forward and rear ends respectively. As the main outer shaft is bolted to this gear wheel and connected by bevel gear to the auxiliary drives, a certain amount of damping is secured owing to impeller inertia.

Mounted on, and driven by serrations from, the hollow main shaft, which is horizontal, a bevel gear wheel meshes with two vertical gear shafts pointing one above and one below the main shaft center line. A distance

Table 1.—Supercharger—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
	*Bore of rotor shaft inner floating bushing.	$\frac{0.62525}{0.625}$	0.[illegible]	$\frac{0.001}{0.00150}$	0.002$\frac{1}{2}$
	Diameter of rotor shaft.	$\frac{0.624}{0.62375}$	0.[illegible]		
	*Bore of rotor shaft outer floating bushing.	$\frac{0.719}{0.71875}$	0.720$\frac{1}{4}$	$\frac{0.001}{0.00150}$	0.002$\frac{1}{2}$
	Diameter of rotor shaft inner float-bushing.	$\frac{0.71775}{0.71750}$	0.716$\frac{1}{4}$		
	*Bore of rotor shaft flanged bushing.	$\frac{0.81275}{0.81250}$	0.814	$\frac{0.00125}{0.00175}$	0.002$\frac{3}{4}$
	Diameter of rotor shaft outer floating bushing.	$\frac{0.81125}{0.811}$	0.809$\frac{3}{4}$		
	Total end clearance between rotor shaft and bushings.			$\frac{0.025}{0.505}$	0.075

* These three clearances added together must not exceed 0.006 in. on any individual engine.

sleeve and adjusting washer are interposed between the gear extension and a ball-bearing inner race, which abuts against a shoulder near the rear

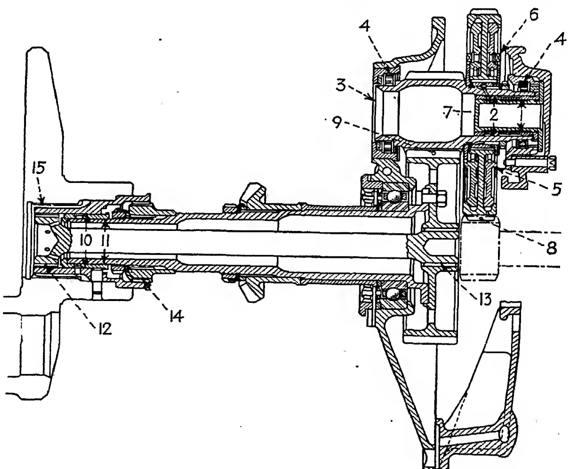


FIG. 18.—Gearing of supercharger. See list of fits and clearances in Table 2.

flange. The whole assembly is secured by a serrated ring nut having a lock plate and washer, the ball bearing providing an end bearing and location of the shaft and supercharger main gear, but the adjusting washer determin-

ing the bevel meshing. The forward end bears in the phosphor bronze bushing which has an annular groove and holes for communicating high-pressure oil to the oscillating surfaces, the rear bearing being mounted in the supercharger gear casing.

An internally and externally serrated bushing is secured to the hollow shaft near its forward end by a ring nut and lock washer, the outer serrations having a rotational clearance with those in the main driving bushing for the purpose already described.

It is usual to retain the casings and gears with a temporary bolt.

Remove this bolt and part the casings, taking care that gears and inner rollers do not fall out. Gear teeth, slipper pads, and roller races can then be examined.

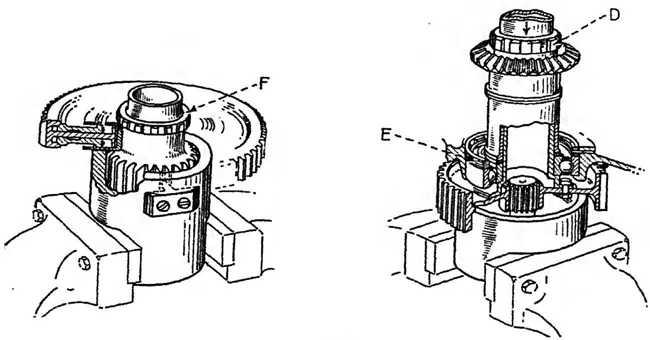


FIG. 19.—Disassembling the spring drive.

Each of the three slipper gears can be removed from its shaft after first bending the tab washer and unscrewing the nut. Mount the assembly in the block (Fig. 19) and unscrew nut *F*. The driving flanges can then be pulled apart giving access to the spring rings. Remove these and keep each set of six slipper pads together, according to the markings.

Assemble the planet gears in casing as follows: plain gear shaft at the top, gear shaft with starter dog on the right-hand ("A") side, and gear shaft with small gear for dynamo drive on the left-hand ("B") side.

Spring Drive.—The main drive gear shaft is positioned endwise by the ball bearing secured at its outer race by a ring nut and washer to adjust end clearance.

Mount the assembly in the vise block (Fig. 19) and unscrew nut *D*.

The shaft can be removed and then the ball bearing, after drawing off the serrated piece, bevel gear shaft, distance sleeve, and washer. These are secured by ring nuts and tab washers. The shaft can then be tapped out of bearing in the direction of the arrow. Take out the spring circlips from ring nut *E*, unscrew the nut (note adjusting washer), and tap out the bearing.

When reassembling, it is important that the correct adjusting washers be interposed both between the ball-bearing inner race and sleeve end and also between the outer race securing nut and casing, the latter allowing an end float of 0.001 to 0.002 in.

Table 2.—Supercharger Gears and Spring Drive—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
1	Bore of floating bushing for intermediate gears.	0.90650 / 0.90625	0.90825	0.001 / 0.00150	0.003
	Diameter of spigot bushing........	0.90525 / 0.905	0.90325		
2	Bore of intermediate gear.........	1.10025 / 1.100	1.10250	0.00050 / 0.00125	0.003
	Diameter of floating bushing.......	1.09950 / 1.009	1.097		
3	End float of intermediate gear shaft.	....	....	0.007 / 0.010	0.015
4	Clearance on diam. between rollers and outer race of intermediate gear roller bearing.	....	....	0.001 / 0.002	0.003
5	Radial clearance between lugs on driving segments and side plates.	....	....	0.025 / 0.050	
6	Side clearance of driving segments in side plates.	....	....	0.012 / 0.014	0.020
7	Bore of slipper gear bushing.......	1.84425 / 1.84375	1.847	0.00175 / 0.00275	0.005
	Diameter of guide plate boss.......	1.842 / 1.84150	1.83875		
8	Backlash between slipper gear and rotor shaft.	....	....	0.010 / 0.015	0.020
9	Backlash between intermediate gear and main driving gear.	....	....	0.008 / 0.012	0.019
	Spring Drive				
10	Bore of crankshaft bushing........	1.516 / 1.51550	1.518	0.001 / 0.002	0.00350
	Diameter of floating bushing.......	1.515 / 1.51425	1.512		
11	Bore of floating bushing...........	1.28175 / 1.28125	1.284	0.00125 / 0.00225	0.004
	Diameter of main drive shaft......	1.280 / 1.27925	1.27725		
12	Backlash between splines and splineways of spindle and bushing in crankshaft.	....	....	0.001 / 0.003	0.010
13	Backlash between splines and splineways of spindle and supercharger gear.	....	....	0.001 / 0.003	0.010
14	Width of splineways in rear end of crankshaft driving bushing.	0.43550 / 0.435	0.445		
	Width at root of splines of driving bushing on hollow shaft.	0.258 / 0.253	0.240		
15	Width of splineways in crankshaft..	0.301 / 0.300	0.305	0.001 / 0.003	0.006
	Width of splines on driving bushing.	0.299 / 0.298	0.294		

MAIN ENGINE PARTS

Pistons and Connecting Rods.—Pistons are forged aluminum alloy, with five rings: three top pressure rings and two drilled scraper rings. One of these is below the piston pin. The piston pin floats in the bosses with

snap rings (circlips) at each end. The permissible weight variation for any one piston in an engine is ½ oz. including the five rings. The construction of pistons and connecting rods is seen in Fig. 20.

Connecting rods are of the forked, or spade, type, also known as marine type. The bearing is a nickel steel sleeve, lined inside and out with a special lead-bronze mixture, divided lengthwise of the bore. The inner lining bears directly on the crankpin. The sleeve is held against turning in the main, or forked, rod. The central, or inner, rod bears on the outer lining of the split bearing, as seen in Fig. 20. This also shows how the rods and caps are held together.

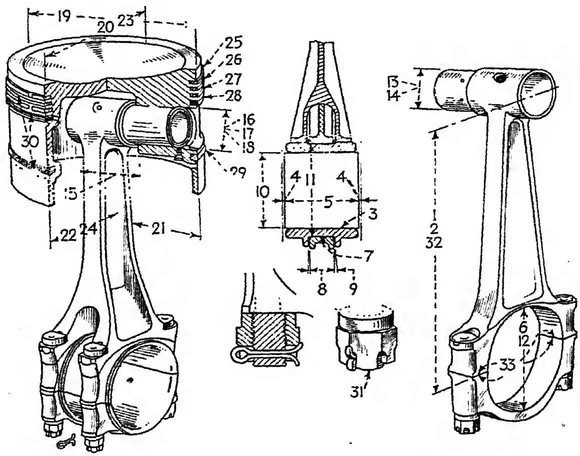


FIG. 20.—Pistons and connecting rods. See list of fits and clearances in Table 3.

The small end of each rod carries a floating phosphor bronze bushing that bears directly on the piston (gudgeon) pin. This bushing has holes drilled in the center so that splash oil can reach the bearing in the rod. The rods should be assembled as the crankpins in the following order: Forked rod first, plain rod on the "A" side; forked rods "Lead," plain rods "Trail." *It is possible to assemble the plain rod with its rear face forward, but this must be avoided by observing the markings when dismantling.* All parts are marked, and it is advisable to reassemble them loosely immediately upon removal.

The lower bearing halves are marked "1–6" and the burned oil must be cleaned off to show the markings which are etched on.

Inspect all bearing metal for breaking away from steel shell and for cracking or undue pitting.

The permissible variation in weight for any one assembled pair of rods, pistons, pins, and rings, in an engine, is 1 oz.

Avoid damage to the bearing metal surface for plain rod by contact with the sharp edges of the latter when replacing. particularly if the rods are assembled while on the engine.

Table 3.—Pistons and Connecting Rods—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
	Error of alignment between small and big ends, checked with mandrels—				
1	Lack of parallelism per in. of mandrel	0.00050	0.002		
2	Twist per in. of mandrel........	0.00050	0.003		
3	*Clearance between bearing block bore and crankpin.	....	....	0.00325 / 0.00375	0.005
4	*End float of bearing block on crankpin.	....	....	0.035 / 0.048	0.060
5	*Width of bearing block..........	2.290 / 2.280	2.265		
6	Bore of big end of plain rod.......	3.47525 / 3.475	3.478		
7	Clearance between bore of big end of plain rod and outside diam. of bearing block.	....	....	0.002 / 0.00250	0.005
8	Width of plain rod big end........	0.812 / 0.810	0.803		
9	End float of plain rod on bearing block.	....	....	0.003 / 0.005	0.012
10	†Ovality of bore of bearing block...	....	0.002		
11	‡Ovality of outside diam. of bearing block.	....	0.003		
12	§Ovality of plain rod big end bore..	....	0.003		
13	Bore of connecting rod, small end..	1.50050 / 1.500	1.502	0.0075 / 0.00150	0.00275
	Outside diam. of gudgeon pin bushing.	1.49925 / 1.499	1.47925		
14	§Ovality of connecting rod small end bore.	....	0.002		
15	Width between gudgeon pin bosses in piston.	1.830 / 1.825	1.865	0.040 / 0.050	0.080
	Length of connecting rod, small end.	1.785 / 1.780	1.745		
16	Bore of gudgeon pin bush........	1.35075 / 1.35025	1.35225	0.00075 / 0.00170	0.00275
	Diameter of gudgeon pin..........	1.34950 / 1.34940	1.34725		
17	Bore of gudgeon pin boss..........	1.350 / 1.34975	1.352	0.00025 / 0.00060	0.00250
	Diameter of gudgeon pin..........	1.34950 / 1.34940	1.34750		
18	‖Ovality of gudgeon pin..........	....	0.001		
19	Diameter of piston at top, measured on axis of gudgeon pin.	5.36650 / 5.36450			
20	Diameter of piston at top, measured at right angles to gudgeon pin axis.	5.370 / 5.368			
21	Diameter of piston at bottom of skirt, measured on axis of gudgeon pin.	5.372 / 5.370	5.360		

* Bearing blocks which are found to be within the limits of wear before being refitted are to be inspected to ensure that the bearing metal is in a serviceable condition. Dimensions to be taken on parallel part of bore which is 1.65 in. wide, a slight chamfer extending each side to the radius.

[illegible] diameter to be within permissible worn dimensions.

‖ Minimum diameter to be such that "permissible worn clearance" for gudgeon pin in piston is not exceeded.

Table 3.—Pistons and Connecting Rods—Fits and Clearances *(Continued)*

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
22	Diameter of piston at bottom of skirt, measured at right angles to gudgeon pin axis.	5.380 / 5.378	5.370		
23	Clearance between cylinder and top of piston, measured at right angles to gudgeon pin axis.	....	....	0.030 / 0.034	0.045
24	Clearance between cylinders and bottom of piston, measured at right angles to gudgeon pin axis.	....	....	0.020 / 0.024	0.035
25	Width of top ring groove..........	0.10050 / 0.09950	0.10450	0.006 / 0.00750	0.011
	Width of top ring................	0.09350 / 0.093	0.08850		
26	Width of second ring groove......	0.10050 / 0.09950	0.10450	0.006 / 0.00750	0.011
	Width of second ring.............	0.09350 / 0.093	0.08850		
27	Width of third ring groove........	0.10050 / 0.09950	0.10450	0.006 / 0.00750	0.011
	Width of third ring...............	0.09350 / 0.093	0.08850		
28	Width of upper scraper ring groove.	0.194 / 0.193	0.198	0.002 / 0.00350	0.007
	Width of upper scraper ring.......	0.191 / 0.19050	0.186		
29	Width of lower scraper ring groove.	0.194 / 0.193	0.198	0.002 / 0.00350	0.007
	Width of lower scraper ring........	0.191 / 0.19050	0.186		
30	Piston ring gap when in position in cylinder.	....	....	0.025 / 0.030	0.085
	Permissible variation in weight of pistons selected for one engine = ½ oz.				
	Permissible variation in weight between any two pairs of connecting rods, pistons, and pins fitted to one engine = 1 oz.				
31	Maximum twist on connecting rod bolts, 22½ deg.				
32	Minimum distance between big end and small end of plain rod.	....	0.888		
33	Big ends of worn or rust-pitted plain rods may be reground in the bore after grinding off a maximum of 0.010 in. from clamping surfaces of each or both halves.				

It is of vital importance that the split pins locking the nuts of both forked and plain connecting rods are a tight fit in their holes and are secured by opening as shown in Fig. 20.

Spare big end bearings are supplied to a finished size inside and out, with an allowance of 0.002 in. in the bolt holes, for parallel reaming in position with the forked rods. The plain rod cap is also parallel reamed in position.

Fits and clearances are given in Table 3.

Lubrication.—A pressure-fed oil hole in each hollow crankpin lubricates the forked rod bore and crankpin. Four holes, two in each half of the bearing block, communicate with two annular grooves formed in the outer bearing surface, to lubricate the plain rod and bearing. Oil is thrown out

upon the cylinder walls and pistons, entering the small end bushing through two holes in the rod eye which has an internal annular groove. Holes at the bushing center lead to the pin bearing surfaces.

Crankshaft.—The six-throw crankshaft is made from a one-piece forging having balance weights formed integral. It is machined all over, nitrogen hardened, and revolves in seven bearings in the crankcase, as described. All journals and crankpins are hollow.

A serrated coupling flange, which also bears the engine timing marks, is spigoted and secured by 12 bolts at the forward end and engages with a drive coupling shaft, connecting the reduction gear pinion.

Faulty rotational replacement of the timing disk is prevented by "off-setting" one of the bolts. Each main journal is fed with high-pressure oil, journals 2, 3, 5, 6, and 7 each having three radial holes, the webs of 2, 3, 5, and 6 being drilled to communicate oil with the six crankpins. These have a single hole on the leading side to direct oil to the big end bearings. The central journal 4 has no blanking plugs. Distribution of the oil to the crankpin and big end bearings is as follows: journals 2 and 6 each supply two crankpins. These are Nos. 1 and 2 and 5 and 6, respectively, crankpins 3 and 4 being supplied by main bearings 3 and 5.

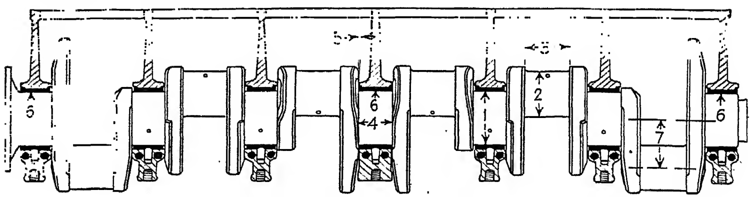


FIG. 21.—Crankshaft fits and clearances. See Table 4.

A steel bushing having serrations which engage the interior of the crankshaft rear journal, and also serrated internally at the rear end, engages with a spring drive shaft.

The bushing is drilled to communicate with an annular space connected with oil from the three journal holes, which are fed from the main bearing supply. A steel dowel locates the bushing endwise in the crankshaft. A steel disk blanks the journal inner end.

Main journals 1 and 4 are not drilled, 4 having no blanking plugs. But No. 1 is fitted with a plug which engages a projection on the drive-shaft end. The remaining four journals are fitted with blanking plugs as are all the six crankpins, each being fitted with chamfered aluminum caps, secured by a single bolt to form an oil-tight space, also convenient for cleaning purposes. See Fig. 21 and Table 4 for fits and clearances.

These spaces provide convenient means for oil communication, three holes being drilled in five of the main journals, the first and the center journals not being drilled. One of the three holes continues into the crankpin web, the pin being drilled to its bearing surface, on the leading side.

End location is effected at the center journal, the bearing flanges allowing a small clearance between the web wearing surface.

Aluminum washers form oil-tight joints between each bolt head and castellated nut, which is always assembled pointing rearward, and is finally split pinned, (cottered) after oil testing, as explained later.

To inspect the crankshaft, mount it on a suitable wooden trestle which will allow it to be rotated by hand. Remove all oil plugs from the journals and crankpins. Thoroughly clean out all foreign matter and finally blow

Table 4.—Crankshaft and Bearings—Fits and Clearances
(For splineways see Reduction Gear and Spring Drive)

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
1	*Bore of crankshaft bearing.......	3.35325 / 3.353	3.355	0.004 / 0.00475	0.006
	Standard diameter of journal......	3.349 / 3.34850	3.347		
	†Diameter of journal after first regrind.	3.344 / 3.34350			
	†Diameter of journal after second regrind.	3.339 / 3.33850			
	‡Journals, ovality...............	....	0.002		
2	Standard diam. of crankpin........	2.77450 / 2.774			
	Diameter of crankpin after first regrind.	2.76950 / 2.769			
	Diameter of crankpin after second regrind.	2.76450 / 2.764			
	§Ovality of crankpins.............	....	0.002		
3	‖Length of crankpins.............	2.328 / 2.325	2.350		
4	‖Length of crankshaft center journal.	1.802 / 1.800	1.817	0.013 / 0.017	0.030
	Width of center journal bearing....	1.787 / 1.785	1.770		
5	End float of crankshaft in center journal bearing..................	....	.....	0.013 / 0.017	0.030
6	¶Lack of truth of center journal when crankshaft is supported by journals 1 and 7 in V blocks. (Errors due to ovality to be subtracted.) (Bowing or progressive deflection)......................	....	0.010		
7	Lack of parallelism of crankpins with journals, per in. length......	....	0.00150		
8	**Limit of bowing or progressive deflection of cylinder joint face on crankcase measured longitudinally......................	....	0.002		

* Bearings found to be within the limits of wear are to be inspected to ensure that the bearing metal is in a serviceable condition. Measurements must be taken on the parallel part of bore which is 1.075 in. wide, a slight chamfer extending each side to the radius.
† Each regrind must not exceed the dimensions given for each stage.
‡ Minimum diam. to be such that "permissible worn clearance" for journals is not exceeded.
§ Minimum diam. to be such that "permissible worn clearance" for crankpins is not exceeded.
‖ When regrinding crankpins and journals care is to be taken to see that no metal is removed from the faces on crank webs.
¶ Dial indicator reading: 0.020 in.
** This limit allowed only at partial overhaul.

out all passages. Inspect carefully for cracks and undue abrasion at the bearing surfaces. Reassemble all oil plugs but omit split pins until later.

Fits, clearances, and wear allowances are given in Table 4.

Camshaft and Rocker Mechanism.—Each cylinder block carries a camshaft and rocker mechanism that is held in place by 14 studs. The cam-

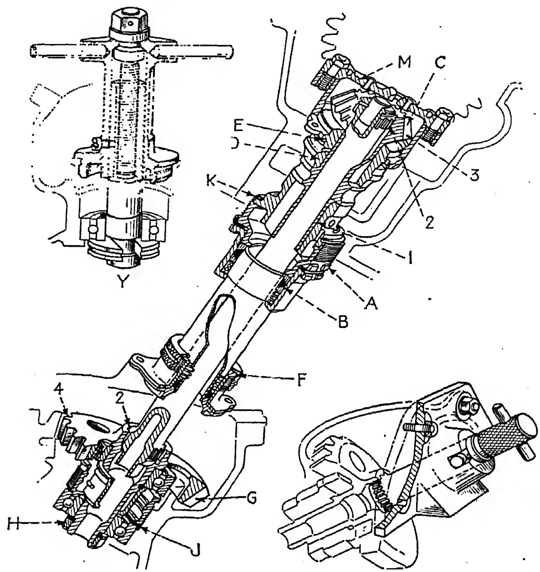


FIG. 22.—Camshaft drives and tools for disassembling them. See Table 5 for list of fits and clearances.

shaft is driven clockwise by a bevel gear, at half crankshaft speed. The camshaft drive shaft (Fig. 22) is inclined from the crankshaft as shown. To remove, detach the lock plate (two screws) from the cylinder and unscrew the lower housing *A* with a spanner. There is no need to separate the two splined nuts unless to dismantle the gland *B*.

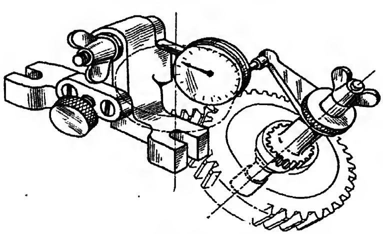


FIG. 23.—Testing backlash in gears *G* in Fig. 22.

If not already removed, the top cover should be detached (two tab washers and cap screws).

Four nuts retain the cover bracket which can then be detached allowing the gear *C* to be pulled out—upward—bringing with it the split aluminum bush *D*. Note and preserve the adjusting washer *E* below the bushing flange. The lower bushing can then be tapped out—downward—using a piece of wood (if necessary)—not metal.

Should the lower gland require to be dismantled, detach the spring circlip from knurled nut *F*, unscrew the latter, releasing the coil spring and allowing the gland and ring to be removed.

Test the backlash of lower bevel gears *G* (Fig. 23). Lock the gear shaft with tool *X*.

Bend the tab washer and unscrew nut *H* from the lower end of the gear shaft in the wheel case and draw out the gear shaft which also holds the upper ball bearing, using extractor (Fig. 24). This can be removed after detaching the sleeve and spring circlip from the shaft. Detach the spring circlip from the sleeve nut and unscrew the nut. Note and preserve the adjusting washer *J*. The ball bearing can then be forced out of the casing, upward, using extractor *Y*.

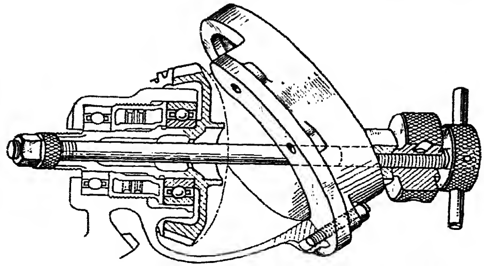


Fig. 24.—Extractor for removing ball bearings.

When reassembling, it is important that adjusting washers *E* and *K* are restored to their original positions.

Wear limits for the important parts of this drive are shown in Table 5.

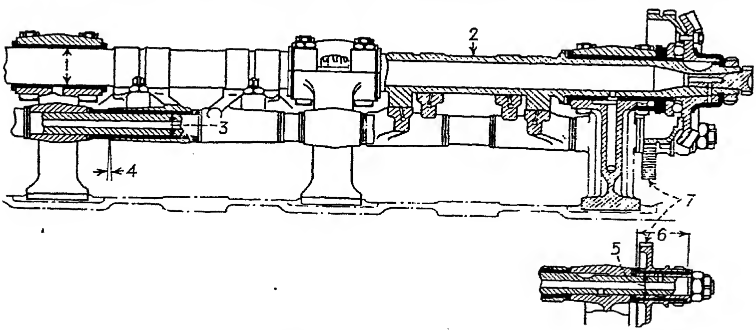


Fig. 25.—Camshaft and rocker mechanism. See Table 6 for fits and clearances.

The camshaft itself is supported in seven aluminum brackets on the cylinder heads, as seen in Fig. 25. Table 6 gives the wear limits for the seven important points.

Cylinder Block and Liners.—Each cylinder block is a single aluminum casting comprising the head and the coolant jacket. "Wet" cylinders of steel are provided, having shoulders which fit against the crankcase and the cylinder block, respectively, at either end.

A coolant joint around the base of each liner is made by means of a rubber ring, spring loaded in an external groove in the liner. As the coolant jackets do not make contact with the crankcase, any leakage from these joints is carried to the outside of the engine.

Table 5.—Camshaft Inclined Drives—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	*Permissible worn clearance, in.
1	Bore of bushings in housing........	1.18850 / 1.18750	1.19050	0.002 / 0.00350	0.005
	Diameter of upper bevel gear shaft.	1.18550 / 1.185	1.18250		
2	Backlash between splines and splineways of driving shaft and bevel gears at each end.	....	....	0.001 / 0.003	0.010
3	*Backlash between camshaft bevel gear and drive shaft bevel gear.	....	....	0.003 / 0.008	0.014
4	†Backlash between lower bevel gear and upper vertical drive shaft bevel gear.	....	....	0.003 / 0.007	0.015

* Adjustable by washers on inclined drive, also by washers on each side of camshaft journal bearings at the driving end.
† Adjustable by washer on vertical shaft and correcting the length of distance piece between bearings on inclined drive lower bevel.

Table 6.—Camshaft and Rocker Mechanism—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
1	Bore of camshaft bearings.........	1.00075 / 1.00025	1.00350	0.00175 / 0.00275	0.005
	Diameter of camshaft journals.....	0.99850 / 0.998	0.90525		
2	*End float of camshaft............	....	....	0.003 / 0.005	0.008
	†Lack of truth of camshaft center journal when front and rear journals are supported on V blocks....	....	0.010		
3	Bore of bushing in rockers.........	0.59475 / 0.59375	0.59850	0.00125 / 0.00325	0.006
	Diameter of rocker shaft..........	0.59250 / 0.59150	0.58775		
4	‡End float of rockers between camshaft brackets.	....	....	0.006 / 0.010	0.020
5	Bore of bushings in auxiliary driving gear on rocker shafts.	0.67550 / 0.675	0.67850	0.00150 / 0.00250	0.005
	Diameter of sleeve on rocker shaft..	0.67350 / 0.673	0.670		
6	Length of sleeve on rocker shaft....	1.152 / 1.150	1.158	0.002 / 0.006	0.010
	Length of bore through auxiliary driving gear bushings.	1.148 / 1.146	1.140		
7	Backlash between auxiliary driving gears.	....	....	0.003 / 0.010	0.017

* Adjustable by washers situated on each side of the camshaft bearing at the driving end.
† Dial indicator reading: 0.020 in.
‡ Adjustable by washers situated on each side of the rocker shaft brackets.

A joint ring of aluminum alloy is arranged between the upper shoulder of each liner and the cylinder block. The joints are maintained by means of 14 long studs which extend from the crankcase through the tops of the blocks. The whole reaction of these studs is taken by the cylinder liners and ensures sound joints at either end of the latter.

Oil leaks from the crankcase are also prevented by another rubber ring which is pressed by the liner flange into a chamfer in the spigot engaging bore.

All but the four end studs pass through stainless-steel tubes, which form oil return ways and make coolant joints at either end by means of two rubber rings at their upper end and one at the lower, held in annular recesses in the block casting and allowing for relative expansion and slight flexibility.

The tube ends are serrated and slightly expanded at their upper ends, the lower ends projecting slightly and extending into a recess in the crankcase where a rubber ring forms an oil-tight joint.

Local distortion of each top joint face, as when subjected to sudden increase or decrease in temperature, is reduced by saw-cutting the casting laterally between each combustion space, thus allowing a certain amount of flexibility.

Six additional studs each side of the block secure clamps which seat against the top flange lower face of each liner to improve the face joint and also prevent liner disturbance during removal of a block. The studs are assembled, initially, from the head upper face, and there blanked off by aluminum plugs. The lower end is accessible by means of a separate cover (one for each stud), which also forms a coolant joint. Each rocker cover forms a joint on an inclined face of the block, providing an assembly to conform with the cowling lines of ther Merlin I engine.

A main coolant pipe delivers to each block at its outer side toward the rear lower end. Coolant circulates through the block, finally leaving via three outlet holes, one at each end and one at the center at the upper end, inlet side (inside) to connect with a main outlet pipe discharging either forward or rearward according to installation requirements.

Each main outlet pipe is built up in two sections, having an intermediate gland. A restriction hole at the rear pipe joint tends to reduce the circulation at this end, and thus even out the temperatures throughout the block. An air vent plug is fitted at the top side of each pipe section—front or rear—for use during filling operations.

Servicing a Cylinder Block.—After a block that has been in service has been removed, it should be secured to the rig (Fig. 13) as described, and subjected to the following two tests, special apparatus being required.

In the event of glycol leaks developing during service, however, either from the top seal rings (inside) or lower rubber joints (outside), the block must be removed and all liners extracted for refitting, as will be described. This must also be done as a routine operation after the period specified for overhaul. Special tools are required for the work.

Air-pressure Test.—Blank off all coolant connections but one. Connect a source of air-pressure supply to the above opening, with a reliable gage in circuit. A hand pump is preferable, as the pressure can be controlled more easily.

Raise and maintain the pressure at 30 lb. per sq. in. and immerse the block in a tank of water at approximately 167°F.

Inspect the following points carefully, either for leaks indicated by air bubbles in the above test, or glycol leaks in the test that follows.

1. The top seal rings (inside)
2. Bottom rubber joints (outside)
3. All inlet and exhaust manifold studs
4. Twelve small side covers (six each side)
5. All core hole plugs
6. Cylinder stud tubes (upper and lower ends)

Glycol Test.—A second test must then be made and special apparatus used. Ethylene glycol, maintained at a pressure of 25 to 30 lb. per sq. in. and at a temperature of 250 to 265°F., must then be circulated through the block; and again all points carefully inspected for leaks. Great care must be taken to eliminate air from the system.

The test should be continued for approximately 15 min. after the base has warmed up to working temperature. Due provision should be made for the protection of personnel while engaged in this test, through contact with the hot glycol and block. A glass case is used at the works and also assists in the heating up.

A leaking stud can often be cured by removing it and smearing the thread with Heldite or other good compound.

Joints at the side covers are made with Klingerit, which must be in sound condition. No jointing compound is to be used.

Core hole plugs must not be retightened or screwed out until block has been allowed to cool, or seizing of the threads may occur. This will necessitate drilling out the old plug, clearing the thread, and fitting a new plug. No jointing compound must be used on the plug joint rings, which must be perfectly flat and in good condition.

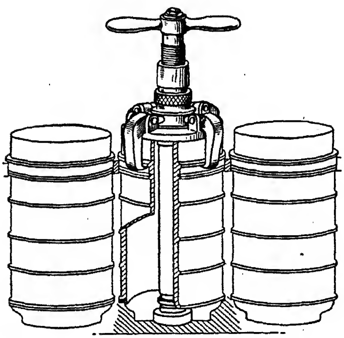


Fig. 26.—Extracting a cylinder liner.

The extraction and renewal of cylinder stud tubes in the event of leaks or damage must be handled so as to avoid bending or distortion.

A white mark can often be seen where a glycol leak has occurred.

Check all pressure gages and temperature meters periodically or there is a risk of damaging the block.

There are five essential points to be observed when refitting liners to a block, namely,

1. The head joint faces must *all be faced down to one level*, determined initially by blocks on a face plate.

2. The total length from the liner face at the crankcase to the combustion head must always be restored to its original length.

3. All top seal rings in one block must be the *same* thickness, the rings being available in thicknesses from 0.080 in. (standard) to 0.115 in. (0.035 in. oversize).

4. All liners in one block must, therefore, be the same length, and if refaced to rectify distortion, must be ground to the same length, each stage varying from 0.005 in. up to a maximum of 0.015 in., according to tolerances listed.

5. New aluminum top seal rings and rubber lower joint rings must always be used, and *no jointing compound.*

Extracting Cylinder Liners.—1. Detach 6 small covers from each side (4 nuts for each) to gain access to 12 side studs and clamps.

2. Release the tab washers, unscrew 12 nuts from the side studs (inside), and remove the 12 clamps.

3. Remove the block from the rig (14 nuts).

4. Immerse the block in water at 167°F. and, using the extractor (Fig. 26) as illustrated, withdraw all liners as quickly as possible.

It is important that the block should be hot when this is done. If there has been any delay, allowing it to cool, it should be heated again immediately before using the extracting tool.

Observe that the liners are numbered "A1 IN.," "A2 IN.," or "B1 EX.," "B2 EX," etc., whichever block is being handled.

Seal rings are radiused at their upper face, that is, the face in contact with the block. As the top seal rings are slightly larger in diameter than the block skirt bore, difficulty may be experienced in removing the liner completely, as the rings usually tend to remain on the liner spigot due to carbon deposit. The procedure, then, is to pry off the ring squarely from each side of liner, using a suitable tool inserted through the clamp stud openings.

After pulling out the liner, the ring can also be removed in a vertical plane and forced through the skirt opening.

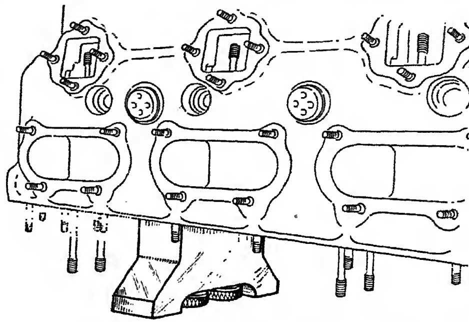


FIG. 27.—Blocks for setting up cylinder in reassembling.

In the case of a block in which one or more joint faces show signs of pitting or other damage, such damaged joint faces must be cleaned up first.

Carefully clean with a small scraper and fine emery cloth (lightly used) round the mouth of the bore of each liner and the recess in the cylinder block around the seal ring, and also the bore into which the liner spigots. Carefully clean away any pieces of rubber from the grooves at the base of the liner and inside the cylinder skirt.

Rest each liner in turn on a faceplate with its bottom flange on two equal steel blocks, one on either side, and measure the height to the top flange face with a dial indicator. The indicator should be used all round the joint face. The object of this operation is to detect any distortion. Any liner that shows a distortion exceeding 0.0005 in. should be set aside for skimming up. This can be done to the extent of 0.020 in. allowing a maximum of four regrinds to be made, each of 0.005 in. Suitable joint rings are obtainable. Where such a trued-up liner is utilized, however, all other liners in that block must also have been trued or reduced to the same extent, the amount taken off being made up with oversize seal rings to bring the depth of all liners back to standard, as later described. The liners are all marked with the letter "S" to indicate they are of standard length; or "S + ½" to indicate that they are 0.0005 in. oversize; or "S − ½" to indicate that they are 0.0005 in. undersize. If one or more replacements are required, new liners must be selected having the same markings.

Carefully inspect the seal ring seating in each cylinder head, making a note of any which may show sign of pitting or damage. Compare with the leakage record already stated.

Attach the two blocks, one to each face of the end rocker brackets, and secure to the two studs by screwing up the knurled nuts tightly by hand (Fig. 27).

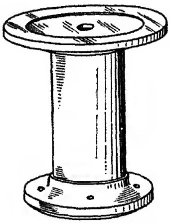


FIG. 28.—Depth gage used in cylinder bore to check height from faceplate.

Invert the block and rest the stands on a clean faceplate. This determines the datum line to be used throughout when recording dial indicator readings.

Insert the depth gage (Fig. 28) in each bore in turn, and measure the height from the faceplate to the upper facing of the gage by means of a clock indicator. This should be mounted on a substantial support to avoid false readings. Do this at four points around the gage, two along the major axis of the block and two at right angles thereto, and record the variations at each of these four points. The object is to discover whether the block is distorted by being bowed—either concave or convex—along its major axis, and also whether any one joint face is distorted. The block must be rejected if found to be bowed more than 0.008 in. The maximum permissible variation from a single plane of the base flanges of all liners, or a part of one, is 0.0005 in. after truing up.

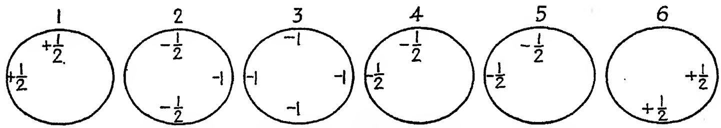


FIG. 29.—Record readings of a slightly defective cylinder block.

A typical record of an unbowed and only slightly defective block appears in Fig. 29. The valves are parts of one one-thousandth of an inch.

The lowest joint facing is the one which must be trued up first, that is, in this case, No. 3. From the indicator readings this appears to be true, but there may be local distortions not readable by the depth gage and dial indicator, therefore it is advisable to trim the face with the tool (Fig. 30). This is provided with a threaded collar having a left-hand thread and locked by means of a wing nut and clamp bolt. This collar can be set to limit the depth of the cut, using a feeler gage. The smallest feeler gage available should be used, probably 0.002 in., and the collar set that amount above the guide. The tool should now be rotated with an even downward pressure. After cutting the 0.002 in., remove the tool and inspect the facing to be sure that it shows sign of having been cut all round. Having carefully brushed out all particles of metal, reinsert the depth gage and check the indicator readings the same all round the top edge. At the same time set the dial to zero, and with this setting make another record of the inaccuracies of the remaining five bores. Face these down to No. 3 with the cutter to within ±0.00025 in.

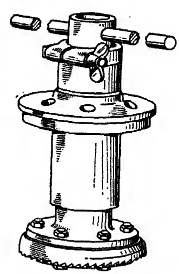


FIG. 30.—Face-cutting tool.

It will be noticed that all the other facings show a slight out-of-truth, and, though this is within the permissible error of 0.0005 in., in view of the

fact that some metal has to be taken off to level them up to facing 3, the opportunity can be taken of correcting these local inaccuracies. This is

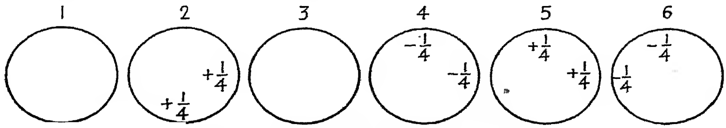


FIG. 31.—Defects recorded after cutting.

done in the following manner:

Screw back the collar of the cutting tool until it is clear of the guide and insert the tool in the bore of the facing to be cut. Let us assume that this is No. 2. It is evident that more metal must be taken from that part of the facing immediately adjacent to bore 1 than from the remainder. To do this, pressure should be thrown on to the tool in a direction toward bore 1, while rotating the same. With a little practice it will be found possible to correct considerable errors in this way.

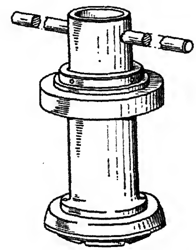


FIG. 32.—Tool for lapping face of cylinder block.

After cutting, the recorded measurements were as shown in Fig. 31.

Then lap the joint facings, using the lapping tool (Fig. 32), and a good lapping compound. It is of vital importance that this lapping tool should be maintained in perfect condition by truing it at regular intervals. The face can be checked by using a standard face plate and Prussian blue.

The lapping process need only be continued at each facing until it is apparent that lapping is occurring as a continuous ring on the joint face.

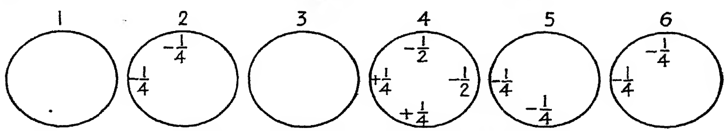


FIG. 33.—Record of cylinders after lapping.

After lapping, the dial indicator readings were as shown in Fig. 33.

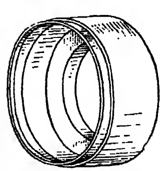


FIG. 34.—Cap gage for reading of joint flanges.

The block was equipped with standard liners, which were lightly lapped in, each in its own bore, as marked, with lapping compound and, when equipped with standard seal rings, gave a final reading on their joint flanges, using cap gage (Fig. 34). The readings were as seen in Fig. 35.

Selecting the Top Seal Rings.—Having lapped all the joint faces to the same level, attach the knurled setting gage to the base of the tool shown in Fig. 36 and set the dial indicator to zero. Remove the setting gage and insert the tool in one cylinder bore, as illustrated.

The deviation of the indicator needle from zero indicates the amount that will be required greater than the thickness of a standard seal ring (0.080 to restore the liner bases to their original length when using a standard in.) liner.

If this reading, therefore, is greater than 0.035 in. (0.115 − 0.080) using a standard liner, the total length cannot be made up to standard by the

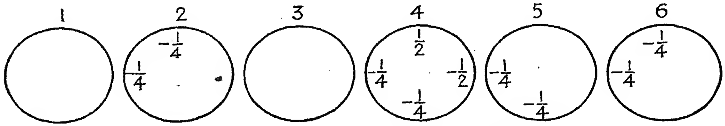


FIG. 35.—Readings with use of cap gage.

maximum oversize joint rings (0.035 in. oversize) and the block must be discarded.

Having determined by above method the final thickness of the joint ring (say, for example, 0.009 + 0.080 in.) that is 0.009 in. indicator reading, a suitable set of new rings should be selected and lapped to 0.089 in. thick, using tool (Fig. 37).

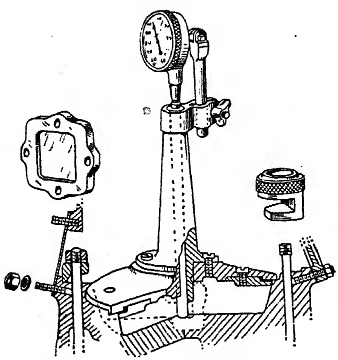


FIG. 36.—Tool for finding thickness of seal ring needed.

If the liner has been subjected to regrinding on the joint flange face, this will reduce the amount that can be cut from the cylinders according to the reduction in liner length (marked on the skirt of liner "S-.005 to S-.015") and a new set of liners (standard length) will be needed when it is necessary to use the full depth of cut with 0.035 in. oversize rings.

A typical example of indicator records of a bowed block is seen in Fig. 38.

In this case the method of procedure is to face up Nos. 1 and 6 first until these show the same at both ends and all round. The intermediate bores are then faced down to this level, each facing being leveled as described on page 100. The same procedure in regard to lapping is then followed, as described on page 101. The recorded readings, after cutting and after lapping respectively, are given in Figs. 39 and 40.

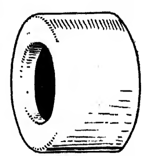


FIG. 37.—Tool used for lapping new rings to proper thickness.

The block must then be well washed to remove every particle of abrasive or metal.

Inserting Top Seal Rings.—As already stated, the seal rings are slightly larger in diameter than the block skirt bore. Insert the ring in a vertical plane and on the block longitudinal center line, pulling it through from below and gaining access from each adjacent bore. The ring, of course, must not be bent or unduly distorted.

When refitting the liners, great care must be taken that no particles of dirt are on any of the joint faces or seal rings.

New rubber joint washers must be fitted, and to facilitate re-entry into the skirt should be smeared with Palmolive grease. The liners should be

pushed home by hand with a sharp final pressure, utilizing the pilot tool (Fig. 41) to facilitate entry of the end.

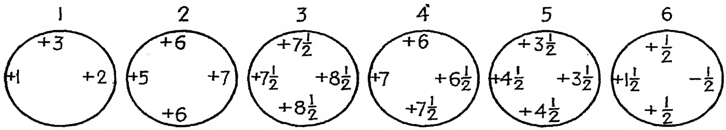


FIG. 38.—This is a record of the defects in a "bowed" cylinder block.

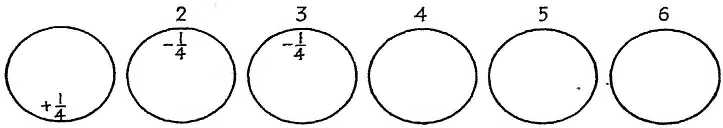


FIG. 39.—Record of a block after recutting.

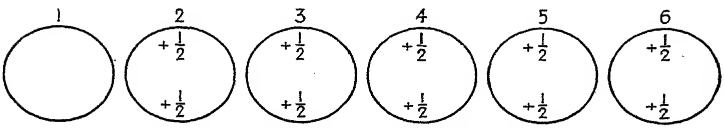


FIG. 40.—The same block after it has been lapped.

The block must then be remounted on a jig and tested under pressure, as already described.

Always wash out the block freely before finally reassembling the liners. Immediately after reassembling, bolt down the block, either to the crankcase or cylinder jig (Fig. 13).

Having secured the block with 14 main studs, attach the side clamps, tab washers, and nuts, and lightly tighten the latter. Fully tighten, uniformly, each pair of side nuts, retaining each cylinder and lock with tab washers.

Replace the side covers, ensuring perfect Klingerit joints.

Fits, clearances, and wear limits are given in Table 7.

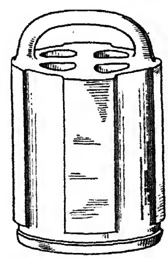


FIG. 41.—Pilot tool for entering liners in cylinder blocks.

STARTING SYSTEMS

Electric Starting System.—The gearing of the electric starting system is shown in Fig. 42.

The sequence of operation of the 12-volt starter motor is as follows:

The turning movement of the armature shaft *N* is transmitted by a splined coupling shaft, to the lower wheel of a compound planet. This rotates in a fixed annulus, the upper wheel engaging and turning slowly in an opposite direction another annulus, the combination being known as a "crypto gear," and giving a reduction ratio of approximately 90 to 1. This in turn drives a bevel gear *C* and includes a ratchet type free wheel *O* which allows a hand-turning gear to be operated without turning the motor. A lay shaft and bevel gear meshed with that on the vertical shaft is geared to the

Table 7.—Cylinders, Valves, and Springs—Fits and Clearances

Ref. no.	Description	Dimensions, new, in.	Permissible worn dimensions, in.	Clearance, new, in.	Permissible worn clearance, in.
1	Bore of inlet valve guide..........	0.43850/0.43750	0.44150	0.00250/0.00450	0.00650
	Diameter of inlet valve stem.......	0.435/0.434	0.431		
2	Bore of exhaust valve guide.......	0.545/0.544	0.548	0.004/0.006	0.008
	Diameter of exhaust valve stem....	0.540/0.539	0.536		
1, 2	Ovality of valve stems*...........	....	0.002		
1, 2	Ovality of valve guide bores†......	....	0.002		
3	Maximum diam. valve seats may be cut using 20 deg. crowning cutter. Diameter of 45-deg. seating:				
	Inlet.........................	1.880/1.875	2.050		
	Exhaust......................	1.830/1.825	2.025		
4	Minimum thickness of valve head after regrinding valve face:‡				
	Inlet valve....................	....	0.058		
	Exhaust valve..................	....	0.080		
5	Minimum dimension between inlet valve, stem face, and cotter groove (after refacing)..................	....	0.387		
6	Minimum length of exhaust valve cap (after refacing)..............	....	0.310		
7	Length of inner valve spring with valve closed.....................	1.600			
	Load on inner valve spring with valve closed, lb.	19.60/18.10	16		
8	Length of outer valve spring with valve closed, in.................	1.682			
	Load on outer valve spring with valve closed, lb.	38.5/35.5	32		
9	Cylinder bore, standard, in.§.......	5.402/5.400	5.405		
	Cylinder bore, oversize, in.§.......	5.409/5.407	5.412		
	Ovality of cylinder bore at center‖.	.....	0.003		
	Ovality of cylinder bore 2 in. from top‖.......................	....	0.006		
	Lack of parallelism of cylinder bore.	....	0.004		
10	Length of standard cylinder liner between spigot faces, in.¶	7.951/7.949			
	Regrinding on cylinder head joint face, first stage, in.¶	7.946/7.944			
	Two subsequent stages of regrinding in steps of 0.005 in.**........	.....	7.934		
11	Minimum length of liner spigot after deducting thickness of oversize ring........................	.....	0.050		
	Longitudinal bowing of cylinder block measured on camshaft bearing faces with straightedge.......	.....	0.008		

* Minimum diam. to be within "permissible worn dimensions."
† Maximum diam. to be within "permissible worn dimensions."
‡ Dimension from lower edge of valve face to bottom of valve head.
§ Measured in center of cylinder.
‖ The greatest diameter of cylinder bore measured in center of cylinder to be within permissible worn diameter.
¶ The amount of oversize or undersize is engraved on the outside of cylinder barrel, *i.e.*, "S + 1" or "S − ½"; "S − ½" or "S − 1." Six cylinders of identical markings to be erected in any one block.
** Use joint washers which are suitably oversize in thickness with cylinders which have been reground on cylinder joint, or cylinder heads which have been refaced.

bendix form of engaging mechanism. This includes also the safety slipping clutch *P*, which protects both hand- and electric-turning gear against backfire. Dog teeth on the bendix shaft engage and turn one of the smaller gears of the supercharger larger planet wheels, finally turning the central shaft Q, which is coupled to the crankshaft by splines, the approximate gear ratio being 393 to 1.

The engaging mechanism is as follows:

Turning of the motor and gears causes a shaft, restrained from turning by a light friction clutch, to move rearward and engage a spring-pressed

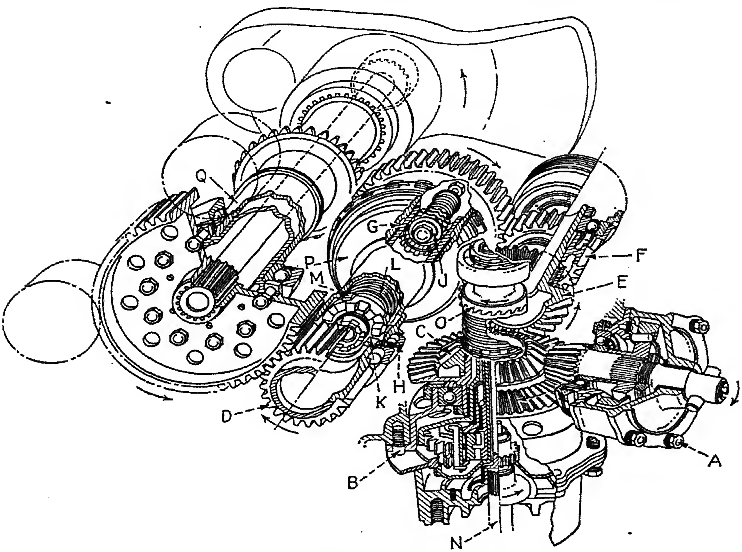


Fig. 42.—Gearing of electric starting systems.

dog with the driven member. Continued movement of the drive then causes the forward movement of the shaft against a stop, thereby forming a solid drive, and causing the small friction clutch to slip. When the engine fires, the engaged dog teeth then overrun, causing withdrawal of engaging shaft. In the event of backfire, the dog teeth remain engaged and, owing to the free wheel in the hand starter mechanism, the gear would remain solid but for the protecting friction clutch which then slips.

The four main assemblies are as follows:

Hand Starter Gear.—This is fastened as an assembly, to a facing on the right-hand side, by six nuts *A*. It comprises a bevel gear shaft engaging at its inner end, the gear train in communication with the engine, and a free wheel as explained. The outer end has a cross pin to engage the starting handle which can, therefore, be rotated in only one direction (clockwise), and so protects the operator against backfire.

The shaft has a ball bearing at the gear end, and a phosphor bronze bushing at the engagement end. An adjusting washer between bearing and gear determines meshing of the latter, the end location then being effected by the ball bearing, which is retained at its outer race in the steel housing by a ring nut and circlip. The steel housing and casing are spigoted together, inclined projections on the housing retaining rollers, rotationally, for the free wheel.

The inner race is secured on the shaft by a ring nut and distance piece, the latter being internally serrated and forming the inner member of a free wheel. Rollers slanting axially with the gear-shaft center line are interposed to engage also with an outer member, which is urged endwise by a corrugated spring to provide what is known as a "jamming type" free wheel.

Epicyclic Starter Gear.—Pointing vertically downward, from the right-hand side, the starter motor is mounted and secured by six studs B to a horizontal facing above. Coaxial with the armature shaft, an epicyclic reduction gear is mounted above it.

An extension from the motor bears an upper flange, having spigoted to it a fixed annulus sandwiched between an aluminum housing which retains a ball bearing above. The lower end of a standpipe extending from the motor retains a sun wheel, endwise, to mesh with each lower wheel of two compound planets carried in needle bearings by a cage supported in bushings above. Serrations at its upper end engage the sun-wheel shaft with a central coupling shaft, having below other serrations to engage the armature shaft. Engaging with the hand-turning gear a bevel gear shaft is supported in the ball bearing referred to, and supports another smaller bevel gear splined and secured above by a ring nut. Meshing of the upper and lower bevel gear is determined by a washer between the gears, and one between the gear and ball-bearing race, respectively, end location then being effected by the ball bearing.

The shaft extends upward, to bear in a phosphor bronze bushing inside and out, and having splines formed toward the upper end. Two other members engage these splines, being held apart by a coil spring, to engage ratchet teeth at the upper end with another member splined to an extension from the moving annulus below. This annulus engages the upper gears of the compound planets and is mounted near its upper and lower ends in phosphor bronze bushings, a roller bearing supporting the extreme upper end. All bearing bushings are phosphor bronze.

Steel adjusting washers are placed as follows: between the planet cage and the bushing flange of the moving annulus; between the face of the ball-bearing inner race and large bevel gear; between the bevel gears; and between the inner shoulder of the upper ratchet piece and the face of the bushing flange.

A special blanking cover should be used during removal, to retain certain gears which otherwise will fall out.

Starter Lay Shaft.—Meshing with the smaller bevel gear C and parallel with the crankshaft center line, a lay shaft engages with another parallel shaft mounted coaxial with and in front of the right-hand planet gear D.

Mounted in needle rollers at its gear end and a ball bearing at the forward end, the lay shaft E carries a spur gear F serrated to the shaft and retained by a nut. The inner race of the ball bearing is also retained by this nut, an adjusting washer being interposed between the gear end and ball race to

determine meshing of bevel gears. A steel housing and ring nut secure the outer race, end location then being effected by the bearing. A housing at the gear end forms a race for the needle rollers which have their inner race formed integral with the gear shaft.

Starter Engaging Mechanism and Safety Clutch.—Meshing with the spur gear *F* a larger gear drives a bendix type engaging mechanism *G* for starting, the gear member being internally serrated to carry friction plates which are spring-loaded to transmit the drive with a safely predetermined torque. Other friction plates are interspaced and engage external serrations on a concentric hollow shaft, on which the gear end and spring housing are rotationally mounted.

Pressed in the forward end of the gear, a bushing bears on the shaft, the whole being supported at that end by an outer roller bearing mounted in the wheel case and at the other end by another roller bearing having its outer race *H* in the supercharger gear case. At the rear end, an inner race is formed integral with the shaft and with the gear wheel at the forward end.

Ten springs are housed in an aluminum casing, spigoted and joined to the gear rear end by a flanged ring nut and circlip, and bearing directly on the hollow shaft. This has an internal thread the coarse pitch, terminating at a shoulder, forward, and also has internal splines at the rear end. These splines engage with another member also splined, but having lost motion which is also internally splined to engage another shaft with a coarse pitch thread to mesh with that in the outer shaft. The inner shaft is hollow and has splines engaging a friction clutch *J* secured to the wheel case by a central bolt for the purpose of restraining the shaft, rotationally, within limits. Turning of the outer shaft, therefore, screws the inner shaft rearward, axially, to engage the dog member *K* through reaction of a coil spring *L* with the supercharger planet gear. Continued movement causes the inner shaft to seat against the dog extension and form a solid drive. Lost motion at *M*, already referred to, allows sufficient rotational movement of outer shaft to enable the dog teeth to be fully engaged before driving torque is secured. The whole unit then rotates, causing the small clutch *J* to slip.

Rotational location of the main spring housing is effected by engaging slots in the periphery.

Friction disks are of aluminum (outer) and saw steel (inner) in both clutches, slip loading being adjusted in the large one by varying the total thickness of the pack. To do this an aluminum disk is fitted at the forward end and is supplied in several thicknesses.

Other adjusting washers are placed as follows: at the rear end, between the outer roller race and gear-shaft shoulder, and forward end, between the outer roller race (each side) and spur gear face. Two circlips retain the smaller friction clutch with the shaft during removal, the clutch setting being determined initially and then locked. A central bolt retains assembly with the wheel case. At the other end a castle nut and lock washer limit end movement of the dog against spring pressure.

VALVES AND IGNITION

Valve Timing.—These engines are provided with a timing disk, pointer, and inspection plug, at the front end of the lower half crankcase.

Figure 43 shows, diagrammatically, the timing gear layout as viewed from the rear of the engine. It also shows

a. Timing disk, markings, and pointer for setting, looking on the *front* of engine.
b. Serrated drive shafts and number of teeth at each end.

c. Direction of rotation of shafts and gears.
d. Number of teeth on each gear encircled.
e. Position of cams when timing.

The camshafts are geared to turn at half crankshaft speed, and the magnetos at 1½ times engine speed.

The vertical drive shaft *E* is geared to an extension from the crankshaft. Inclined shafts *C* and *D*, transmit the drive through bevel gears to each camshaft marked "A" unit (right-hand side), and "B" unit (left-hand side), their engagement being by serrations at each end. The left-hand "B" side shaft *C* is shown disengaged to allow the camshaft to be turned independently of crankshaft, as when timing cylinder B1.

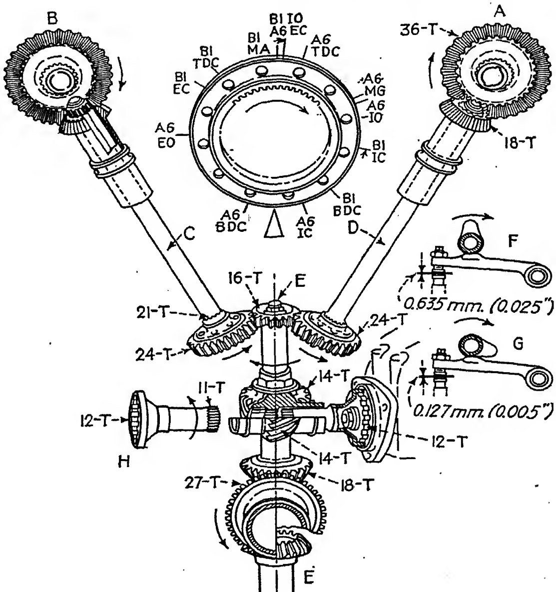


FIG. 43.—Diagram of valve gearing to be used in timing engine.

It should also be emphasized that, if valve timing is to be effected after the magnetos have been timed, as, for instance, when the camshafts have been removed, or the drive shafts *C* or *D* disengaged and the valve timing upset, *one* magneto distributor cover should be detached.

It can then be determined that the magneto points are breaking with, say, the four valves in cylinder A6 closed and distributor pointer at the corresponding marking, namely A.1.6 or A.E.6, according to magneto. (See Magneto Timing.)

Time the engine as follows:

1. Disengage the camshaft serrated drive shaft by lifting the upper end.

2. Either by rotating the propeller shaft (when assembled) or using the hand starter gear, set the crankshaft to timing markings A6 I.O. This means that the inlet valves in the rear "A" unit (right-hand) cylinder should just be opening according to the timing setting. Set either of the inlet valve tappet clearances as shown at *F*, that is 0.025 in.).

3. Insert a 0.005-in. feeler between the tappet and valve stem, with the rocker at the base of its cam as above.

4. By means of a box wrench turn side camshaft "A" in the direction of the arrow until the feeler is just tight, that is, the cam is just about to lift the valve, as shown at *G*.

5. Without moving either the camshaft or crankshaft, rotate the splined drive shaft *D* in stages, until a position is found when it can be fully engaged in the serrations as shown. This may necessitate a *very slight* movement of camshaft, but only within 1 deg., and all positions of the vernier adjustment produced by the 19 and 21 serrations at the upper and lower ends of the driving shaft should first be tried.

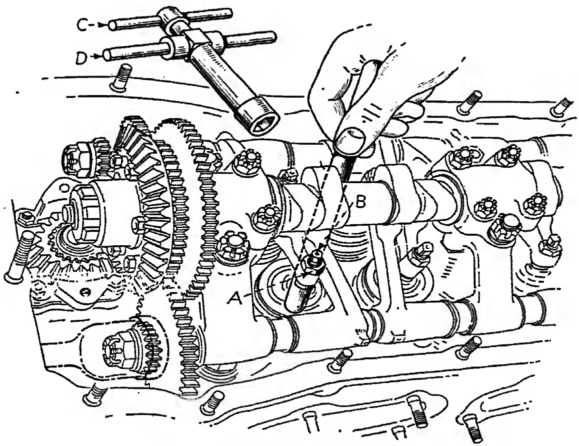


Fig. 44.—Adjusting tappet clearance.

6. Replace and secure retaining cover.

7. From position A6 I.O. rotate crankshaft 60 deg. *in the direction of the arrow* to position B1 I.O. B1 indicates the front cylinder of the left-hand block.

8. Release the left-hand drive shaft *C*, to enable the camshaft to be turned independently of the crankshaft.

9. Set the inlet tappet for the cylinder B1 as before, insert a 0.005 in. feeler, and rotate the left-hand camshaft in the direction of the arrow. Engage the serrated shaft *C* as before, to its nearest setting, and secure with cover.

10. Secure both the drive-shaft casings to the wheel case.

11. Finally, set all tappets to 0.020 in. clearance.

Alternatively, the valves may be timed on the inlet closed (I.C.) markings, but the camshafts will then have to be rotated in the other direction (counterclockwise) until the feeler gage is just tight.

Adjusting Tappet Clearances.—Engage the combined key wrench, shown in Fig. 44, with tappet lock nut *A* and tappet screw *B*. Hold the handle *C* and turn handle *D* in counterclockwise direction to slacken nut *A*. With the rocker pad at the base of the cam (that is, *not on the cam contour*), insert the 0.020 in. feeler, as shown. If the feeler cannot be inserted, unscrew tappet *B* until it can.

Holding handle *D*, turn *C* (and tappet *B*) until the feeler is just tight, and lock the nut *A* by turning *D*. Check that the final setting has not been disturbed during the locking of nut *A*, and that the valve is not being held off its seating while the feeler is inserted.

Two timing positions will be seen on the disk, namely, A6 M.A., and B1 M.A., and either may be used, but each distributor must be set accordingly (see Figs. 43 and 45). For example, if mark A6 is used, the distributor pointer of each magneto must be set pointing to the A6, or, alternatively, at contacts B1 if position B1 is used.

The ignition leads, of course, must not be changed about or timing will be useless. It is assumed that the distributor covers are detached, and that valves have already been timed. Be sure that contact breaker points are 0.012 in. apart *when in the fully advanced position.*

Time the magnetos as follows:

1. Turn the crankshaft in the direction of the arrow until one of the above markings, say A6 M.A., registers with the pointer mark. All valves must be closed in cylinder A6, since the engine must be on its compression stroke. If this is not so, rotate the engine through 360 deg. (one complete revolution).

2. Fully advance the "B" side magneto contact breaker, and turn the armature until the large distributor pointer registers with contact marking A.E.6, and the contact breaker points at *L* are just breaking. This can best be determined by the use of a pilot lamp and battery in circuit with the contacts.

3. Make certain that the correct side pointer is registering, as there are two rows of six leads and two main pointers.

4. Be sure that the armature is not turned, rotate coupling *H* in stages until it can be engaged at both ends and the magneto pushed into position. This may necessitate several trials.

5. Secure the magneto, using paper joint, three nuts, and washers.

6. Without turning the engine, engage the other side magneto, exactly as described before, except that the distributor pointer will register with contact A.I.6. Secure the magneto.

7. Replace each distributor cover and metal screen.

Insert the 12 terminals (it is assumed that the marking plate is attached) and secure with two bolts for each magneto.

Magneto Timing.—It will be seen from Fig. 43 that each magneto is driven by a separate shaft *H* from a gear coupled to the crankshaft. It is only necessary, therefore, to set the crankshaft in the correct position and relationship to valves, since the shafts *H* have 11 and 12 driving serrations, thereby allowing a vernier adjustment when engaging the magnetos.

Both magnetos must be timed to spark together, in the same cylinder at 45 deg. before top dead center, with the "make and break" control in the fully advanced position, that is, toward the front of engine when the magnetos are attached.

Ignition Wiring.—As can be seen in Fig. 45, the right-hand magneto carries 12 high-tension terminals leading to the central conduit and the spark plugs on the inlet side of the cylinders. The left-hand magneto has similar terminals from the plugs on the exhaust side. Should it be necessary to remove the exhaust fittings the following method is recommended:

1. Unscrew three nuts from each exhaust side to release clips, and also the nut below the supercharger bend.
2. Remove two bolts and disconnect the terminal cover from the right-hand magneto.
3. Pull off the distributor cover and mark the position of the distributor.
4. Disconnect the control from the magneto arm (two screws) and remove the magneto and coupling.

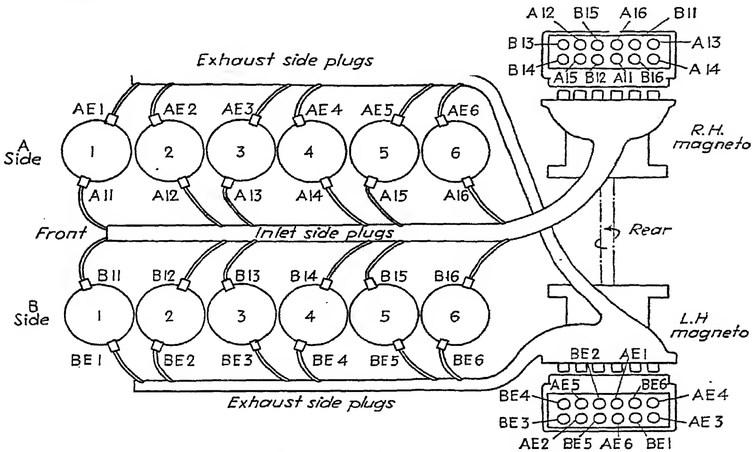


FIG. 45.—Ignition wiring from both magnetos.

The right-hand side conduit can then be drawn through to the left-hand side, under the supercharger bend. Great care must be taken to avoid damage or undue distortion of the braided connections, bends, Bakelite sleeves, and springs.

Magneto.—Each magneto fires one plug in each of the 12 cylinders, as explained, and is marked according to its respective side, namely, "A" for the right hand (A) side of the engine and "B" for the left-hand (B) side. Figure 46 shows the left-hand magneto with its high-tension distributor cover and contact breaker cover removed. The contact breaker housing is also shown separately at the left-hand side to indicate the low-tension connection *H*.

The directions of rotation are also indicated, the right-hand magneto turning in an opposite direction when viewed on its contact breaker end, namely, clockwise; the left-hand magneto turning in a counterclockwise direction when viewed on its contact breaker end. By reference to the drive, however, it will be seen that the two horizontal drive shafts and

magneto armatures all rotate in one direction when viewed from one end only.

The hand starting and main high-tension distributor pointers are seen at *A* and *B*, respectively. The rear pair are shown in the correct position for replacing the distributor cover, there being two pairs placed at 180 deg., but offset axially to correspond with the points *W*. This makes face joints against the felt *C* and *D*, the cover being slid endwise into place and not pushed downward, or felt *C* may foul the distributor gear teeth.

As the ridge *G* separates the pair of contacts, it cannot be engaged in the correct manner while the front contacts are in the way.

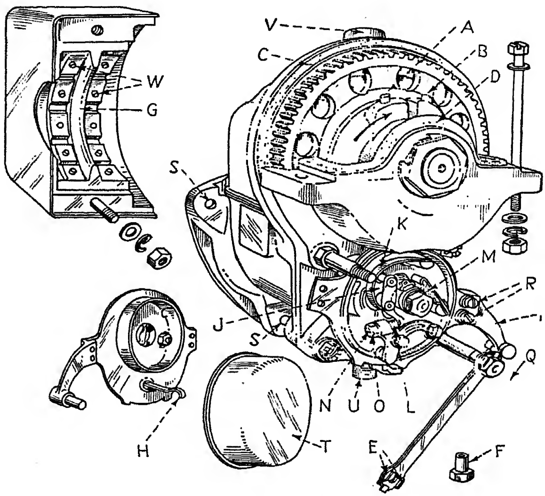


Fig. 46.—Details of Rolls-Royce magneto for use in timing.

In order to remove the contact breaker cover *T*, push one end of spring plate toward the magneto and so disengage tabs *E* from nut *F*, allowing the latter to be unscrewed by hand and the plate swung clear.

The contact breaker is shown at *J*, the return spring at *K*, the contacts at *L*, and the felt pad for cam lubrication at *M*.

The adjustment of contacts *L* is effected as follows:

Holding the screwed end *N* with a screw driver, slacken off nut *O* slightly with the appropriate spanner supplied by the magneto makers and move the control arm *P* to its extreme position in the direction of the arrow *Q*. This is the fully advanced position. Move the armature shaft until the fiber contact pad is on the peak of one cam. This is important since the eccentric mounting of the contact breaker housing produces a different gap clearance when in the fully retarded position. Insert the feeler gage, 0.011 in. (0.013 in. max.) between contacts, and adjust the latter by the screw driver until the feeler gage is just tight; then tighten nut *Q* without upsetting the adjustment.

Two screws *R* form a ready means of disconnecting control arm when removing a magneto from the engine. The flange is spigoted to the wheel case and retained by three studs, two of the holes being seen at *S*.

A ground connection for switching purposes is seen at *U*, and a terminal connection for a hand starting magneto or booster coil at *V*.

The 12 high-tension points are indicated at *W* and connect with spring-loaded plungers in the ignition wire terminals.

In order to remove the coupling flange, the magneto should be secured in a fixture in a vise and, after releasing the locking tab, the retaining nut screwed off. Remove Woodruff key. The same fixture may also be used in a similar manner when replacing the flange.

SECTION IV

WRIGHT CYCLONE ENGINES

The illustrations show a 14-cylinder, double-row Cyclone engine of the 1,600–1,700 hp. type, built by the Wright Aeronautical Corp., Paterson, N.J. Figures 1, 2, and 3 not only show the construction but also give the names of many of the parts. A number of the subassemblies are also shown since they give an excellent idea of the relation of the parts to one another. In some cases, the parts for the front and the back row of cylinders are somewhat different, but not enough so to warrant showing both.

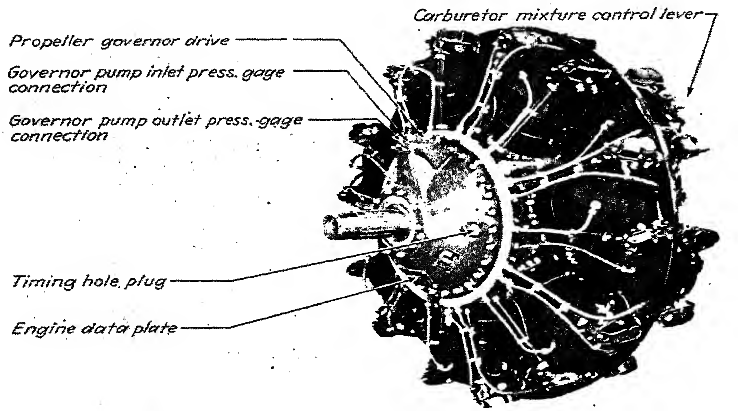


FIG. 1.—Three-quarter *left front* view of Wright 14-cylinder Cyclone engine.

The Wright Double-Row Cyclone 14, series GR2600, has the following characteristics:

Cylinder bore 6.125 in., stroke 6.312 in. Displacement 2,603 cu. in.
Compression ratio 6.85 on the A2A and A2B series and 6.30 on the A—A and A—B series.
Rated r.p.m. 2,300; cruising r.p.m. (of crankshaft) 1,900.
Propeller shaft, spline size, S.A.E. No. 50.
Length of engine 62.06 in.; 70.06 in. with extended propeller shaft.
Diameter of engine 55 in. These are bare engine dimensions.
Weight 1,950 lb. with usual propeller shaft and 2,017 lb. with extended shaft.

The direction of rotation of the propeller shaft is clockwise as viewed from the rear or magneto end of the engine. The "right" and "left" sides of the engine are referred to as viewed from this position. The firing

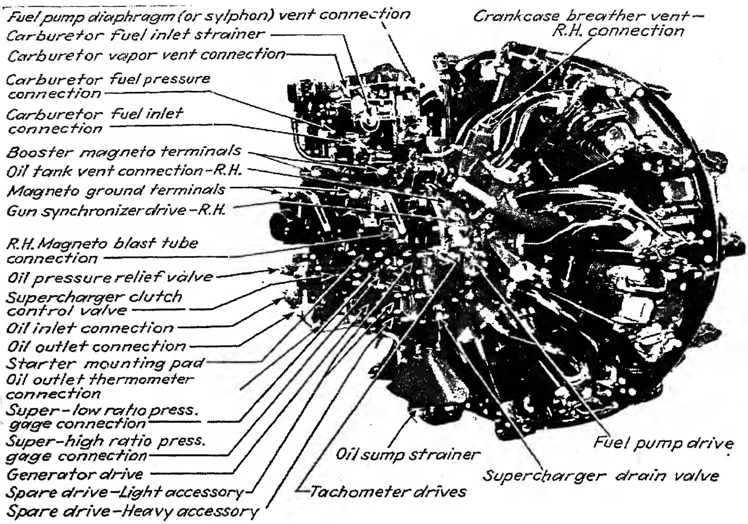


FIG. 2.—Three-quarter *left rear* view of Wright 14-cylinder Cyclone engine.

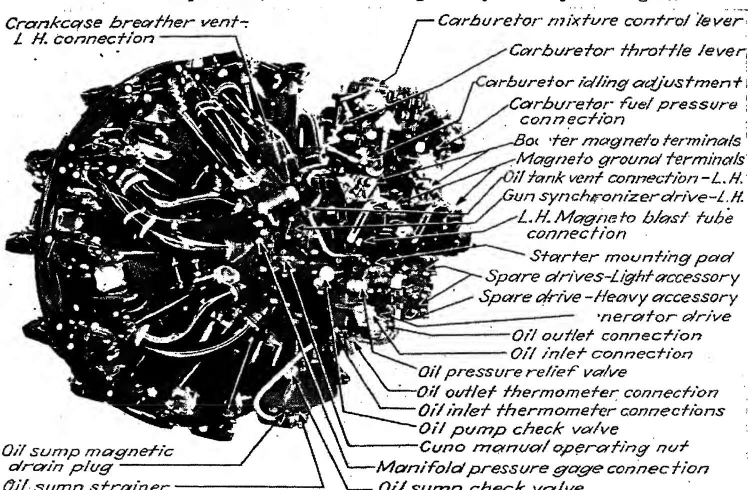


FIG. 3.—Three-quarter view of ***right*** side of 14-cylinder Cyclone engine.

order is 1, 10, 5, 14, 9, 4, 13, 8, 3, 12, 7, 2, 11, 6, viewed from the rear. The cylinders are numbered consecutively in a clockwise direction around the engine, starting with cylinder 1 which is the top cylinder in the rear row and continuing with cylinder 2 which is the top cylinder to the right of the center line in the front row. By this designation all odd-numbered cylinders are located in the rear row and all even-numbered cylinders in the front row.

The direction of rotation and ratio to crankshaft speed of the various accessory drives are as follows, with the exception of the gun synchronizers which are in relation to the propeller shaft speed as noted:

Accessory	Rotation	Viewed from	Ratio of drive to crankshaft speed	
			C14A	C14B
Starter	Clockwise	Rear of engine	1 to 1	1 to 1
Generator	Clockwise	Rear of engine	1.5 to 1	1.38 to 1
Magneto:				
Right	Clockwise	Rear of engine	0.875 to 1	0.875 to 1
Left	Clockwise	Rear of engine	0.875 to 1	0.875 to 1
Fuel pump	Counterclockwise	Right side of engine	1 to 1	1 to 1
*Dual accessory drive:				
Upper	Counterclockwise	Rear of engine	1.5 to 1*	1.5 to 1
Lower	Counterclockwise	Rear of engine	1.5 to 1*	1.5 to 1
Reduction gear	Clockwise	Rear of engine	16 to 9	16 to 9 or 16 to 7
Propeller governor shaft	Counterclockwise	Top of drive	0.992 to 1	0.992 to 1
Gun synchronizer:				
Right	Counterclockwise	Right side of engine	Propeller shaft speed	Propeller shaft speed
Left	Clockwise	Left side of engine	Propeller shaft speed	Propeller shaft speed
Tachometer (mounted on combination fuel pump and tachometer drive):				
Upper drive (C14A)	Counterclockwise	Right side of engine	0.5 to 1	0.5 to 1
Lower drive (C14A)	Clockwise		0.5 to 1	0.5 to 1
Upper drive (C14B)	Clockwise	Right side of engine	0.5 to 1	0.5 to 1
Lower drive (C14B)	Counterclockwise		0.5 to 1	0.5 to 1

* The dual accessory drive gears may be changed to obtain various ratios; therefore, the ratio of the drive to crankshaft speed will vary depending on the type of accessory to be used.

GENERAL INSTRUCTIONS

Cylinder Hold-down Stud or Cap-screw Location.—The following method has been established to determine the exact location of any given cylinder hold-down stud, cap screw, or cap-screw hole in the crankcase. The studs, cap screws, or cap-screw holes will be referred to as No. 1, 2, 3, etc., around the entire pad in a clockwise direction beginning with the first stud to the left of the longitudinal center line of the cylinder at the front of the engine, viewed from the propeller end and looking down on the pad. The number of the pad will be referred to as the number of the cylinder which it mounts in each case.

Inspection of Replacement Parts.—Certain assemblies and detail parts supplied for replacements on Wright engines require line reaming or similar operations at assembly on the engine. Whenever possible, special fixtures are used to perform these operations during manufacture, to eliminate this machining at assembly. In either case, wax or semisolid grease is often used to fill oil passages where metal chips from the machining operations might otherwise collect. If the wax or grease used for this purpose is not completely removed before the engine is assembled, obstruction

of the lubrication to certain bearings or other parts may exist. Failures or serious damage to the engine may result from such obstruction.

It is therefore recommended that whenever spare parts are to be assembled in an engine, an inspection be made to ensure that all oil passages are clear. Extreme care is taken in the manufacture of spare parts to ensure that oil passages which have been filled prior to machining operations are thoroughly cleaned out before the parts are shipped. As an additional precaution, however, it is recommended that operators inspect these parts for clear passages before assembly.

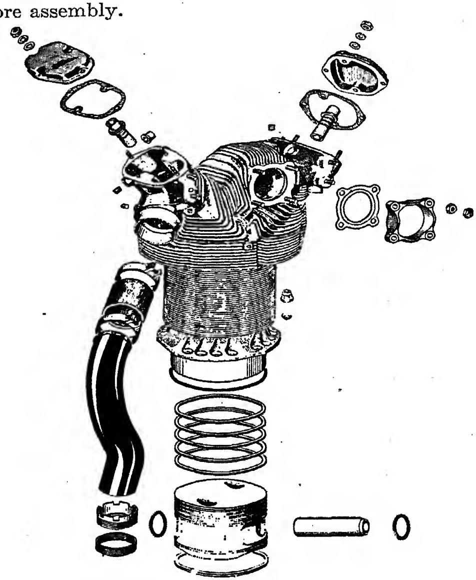


FIG. 4.—Rear-row cylinder assembly.

In the past the Wright Aeronautical Corp. used letters prefixed to the engine displacement, followed by letters and figures, to designate the various engine models. This system has been recently discontinued. In the future, engine models may be identified under the new designation system in accordance with the following list:

Former Designation	Present Designation
GR2600A Series	C14A
GR2600B Series	C14B

Experience of the Wright Corp. indicates that the "top overhaul" which was formerly practiced is no longer necessary in view of the fact that valves and piston do not often now require attention before the rest of the engine. Engines should of course be checked at stated periods; should it be necessary to remove one or more cylinders, owing to loss of compression, this should be done.

To prevent any misunderstanding of the terms used in connection with the Wright engines the following explanation of terms is given:

Front. Propeller end.
Rear. Antipropeller end.
Right side. As viewed from rear of engine.
Left side. As viewed from rear of engine.
Horizontal. Position as in level flight.
Inverted. Upside down, carburetor toward ground.
Nose down. Propeller end pointing downward.
Nose up. Propeller end pointing upward.
Direction of rotation. Clockwise or counterclockwise as viewed facing rear of engine.
Accessory rotation. Clockwise or counterclockwise as viewed facing accessory drive.

The illustrations that follow show some of the more important parts of the engine; the grouping of the parts makes it easy for the men in charge

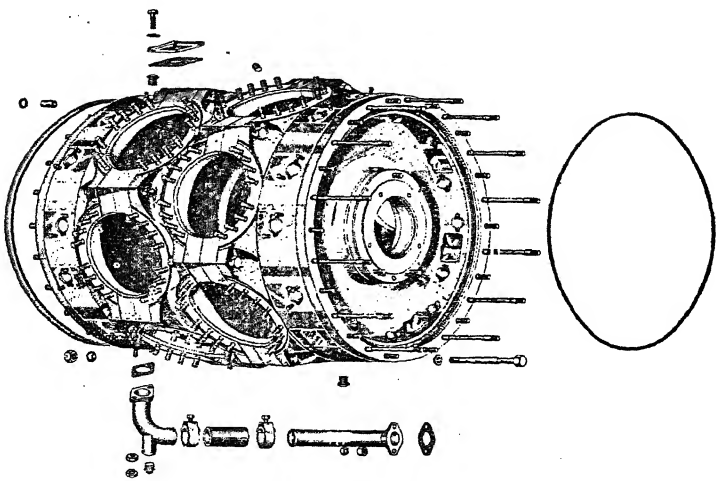


Fig. 5.—Main sections of crankcase.

to reassemble an engine that has been torn down for overhaul. The cylinder barrels are of nitrided steel with aluminum heads shrunk in place. The parts grouped in Fig. 4 show the sections of the rear-row cylinder assembly. The valve seats are shrunk into the heads; valve guides and spark-plug bushings are of bronze. The crankcase is of an aluminum alloy, as is the supercharger housing, these being shown in Figs. 5 and 6. Figure 7 shows the front section of a crankcase and Fig. 8 the supercharger near the housing.

Crankshaft construction, shown in Figs. 9 and 27, is in three parts. The center section contains both crankpins 180 deg. apart, with the front and rear cheeks clamped on. This permits the use of solid-end master connecting rods, as in Fig. 11. The center bearing of the crankshaft is in

halves, as in Fig. 9. The crank cheeks are of hardened steel and the counterweights are designed to dampen out crankshaft vibration. Figure 10 shows extended propeller shaft assembly.

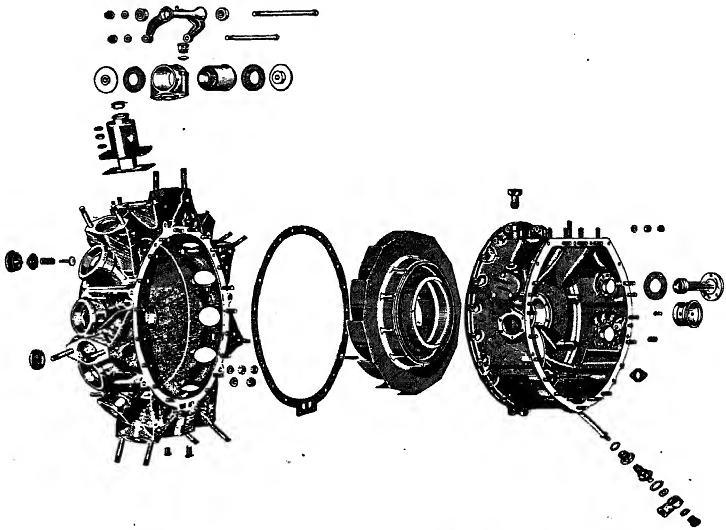


FIG. 6.—Assembly of supercharger housing and diffuser plate.

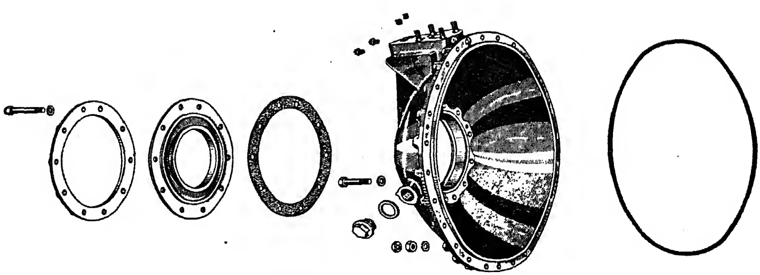


FIG. 7.—Front section crankcase assembly without extension.

The master connecting rods are of the banjo type and have six articulated rods that work on knuckle pins, as is customary in engines of this type.

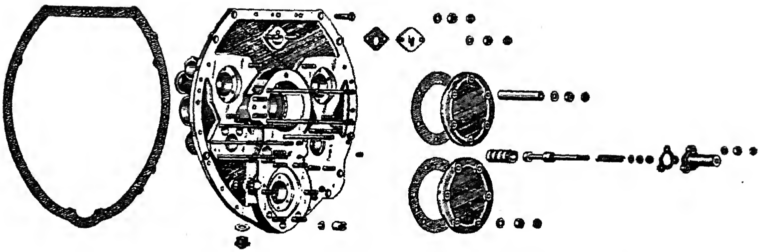


FIG. 8.—Assembly of supercharger near housing.

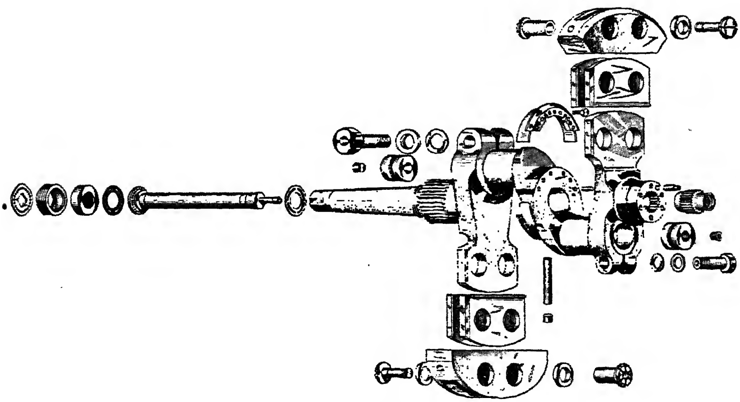


FIG. 9.—Parts used in crankshaft assembly.

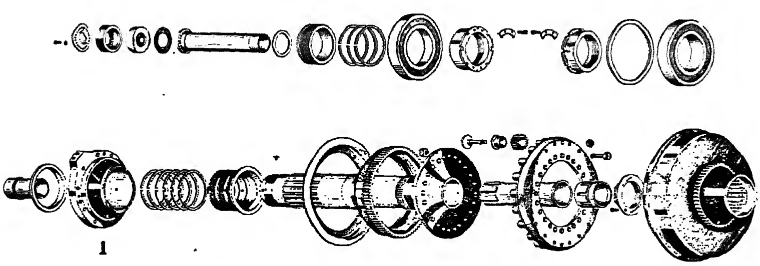


FIG. 10.—Extended propeller shaft assembly.

The pistons are aluminum heat-treated die forgings with five rings, one being below the piston pin. Garter spring retainers having a 45-deg. chamfer on each side are used at the ends of the piston pins.

The valves are operated by two cams, one at the front and the other at the rear. These cams and their drive assemblies are seen in Fig. 12;

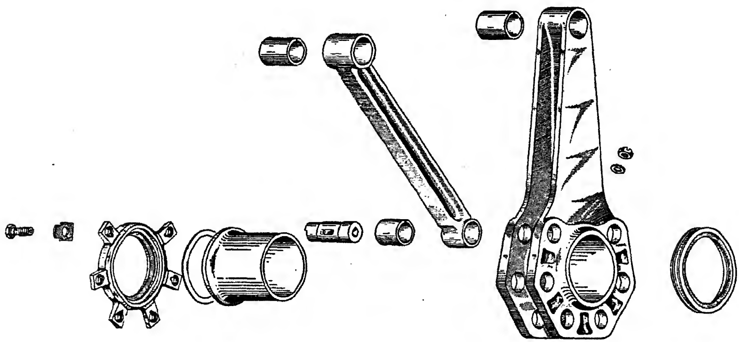


Fig. 11.—Front master rod, articulated, or link, rod, and end seal assembly.

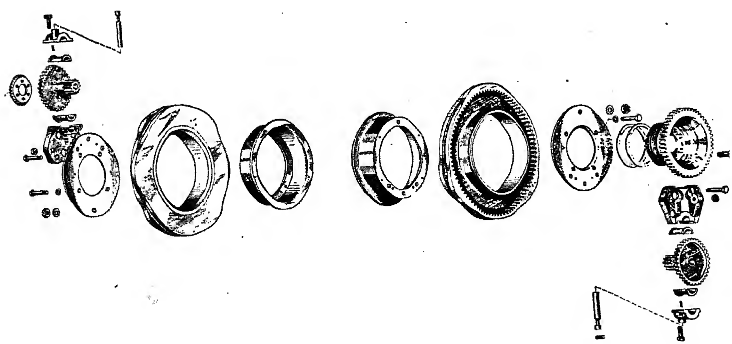


Fig. 12.—Assemblies of cam and cam drive.

they are not interchangeable. Valve operating parts are seen in Fig. 13, which shows the roller valve lifter, its guide bearing, the push rods, and its cover. It will be noted that there are three springs, one inside the other.

Supercharger parts, including the impeller and its shaft assembly, are shown in Fig. 14. The impeller is of aluminum alloy and runs at seven

times crankshaft speed in the single speed assembly. A two-speed supercharger assembly gives ratios of 7.14 and 10 times the crankshaft speed.

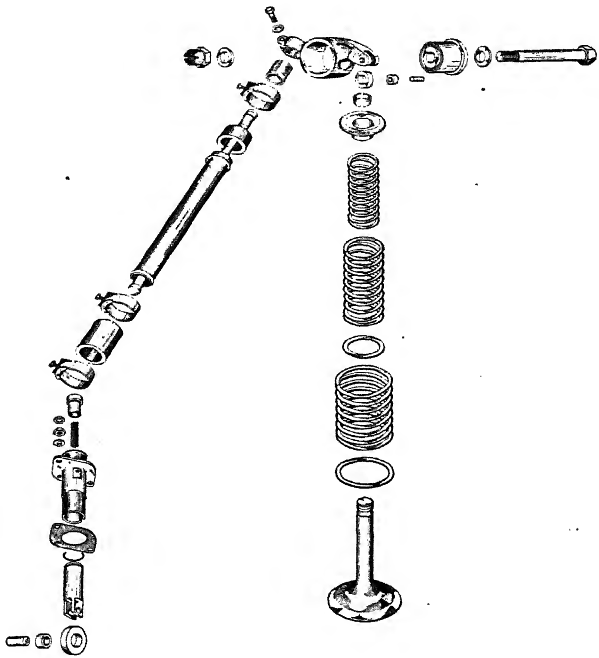


FIG. 13.—Valve mechanism parts.

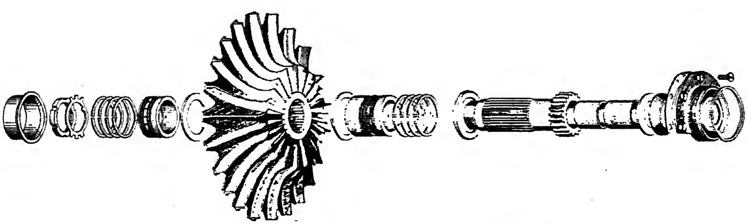


FIG. 14.—Parts of impeller and shaft assembly.

Other assemblies shown are the accessory drive and starter shaft, the tachometer, fuel pump, and magneto drives, and that for the dual accessories (Figs. 15, 16, and 17).

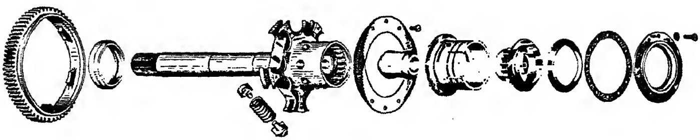
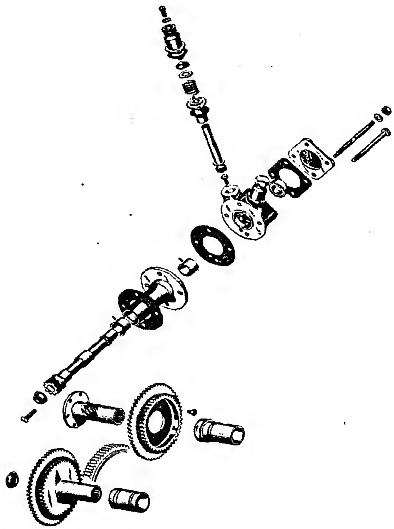


Fig. 15.—Accessory drive and starter shaft assembly.



. 16.—Tachometer, fuel pump, and magneto drives.

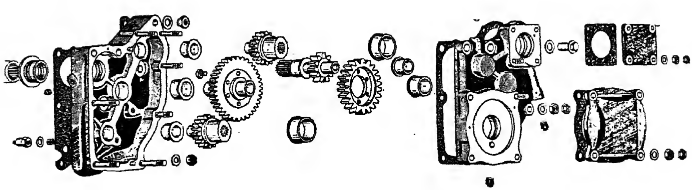


Fig. 17.—Assembly of dual accessory drives.

If engine is received in a crate, first remove the hold-down bolts and lift with a 2-ton crane. Remove the mounting plate while the engine is suspended from the crane, mount the engine on a stand, and lock it in normal flight position. Protect the thread on the end of the shaft with a cap. Remove the spark plugs and put in vented plugs that relieve compression; at the same time, keep cotters, nuts, and washers out of the cylinders. Remove carburetors and outer accessories.

The data plate on the engine tells the position of the cylinder with the master rod. Turn the crankshaft until the front row cylinder *next* to the master rod is on top center. In tearing an engine down remove the master rod cylinder last.

THE ENGINE IN DETAIL

Sectional views of the engine and of the single-speed supercharger are shown in Figs. 18 and 19. A study of these will show the construction

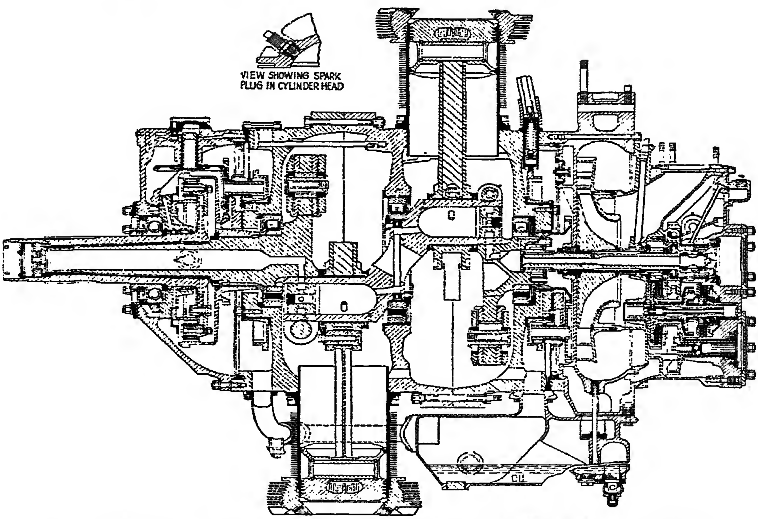


Fig. 18.—Section through both banks of cylinders showing bearings and oil passages.

of the engine and be of great service to those whose job it is to tear them down and reassemble them. Some of the detailed operations are seen in the illustrations that follow.

The piston pins are of the floating type, held by spring retainers in a groove in the piston. These are removed with a special tool, as in Fig. 20. The flat side of the tool is inserted between the coils of the spring, the tool turned 90 deg. so the fulcrum rests on the piston. Pushing the tool toward the engine pulls the spring out of the groove. Use the hand to prevent the spring from flying out.

To remove the piston pin use the puller (Fig. 21), which has a sling, padded where it contacts the piston, and a hole for the pin to go through.

Turning the screw in the nut that rests on the upper end of the pin forces the pin out through the hole in the strap.

For disassembling the crankshaft and crankcase assembly, the stand shown in Fig. 22 is used, together with a hoist to lift the engine into place. The crankshaft is held in the two split bronze bearings. The rear counterweight on the crankshaft should be approximately in the top position.

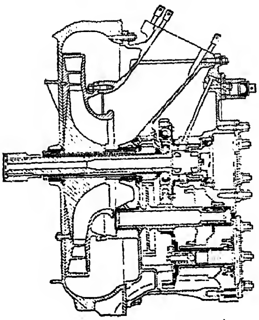


Fig. 19.—Single-speed supercharger drive.

After the locked wires and cap screws are removed, remove the gear, accessory drive shaft coupling, nuts and washers holding the crankcase together. Using aligning bars as in Fig. 23, separate the crankcase sections. The rear main roller bearing will separate when the rear section is removed, leaving the inner race on the crankshaft. Remove the rear main bearing inner race with the special tool, as in Fig. 24.

The rear crankshaft cheek comes next, the cap screw being removed as in Fig. 25, after the cotter pin and locks are taken off. Next the rear section of the crankshaft is removed as in Fig. 26. This is done by spreading the split end with proper tools. The rods are then removed from the pin. Then the center section of the crankshaft is removed as in Fig. 2 allowing the other rod assembly to be taken off its crankpin.

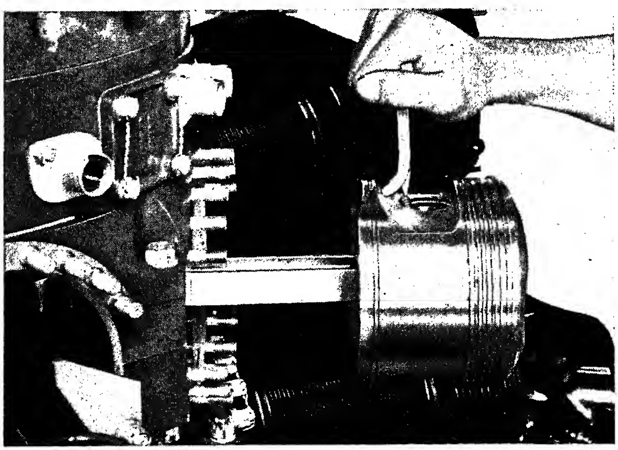


Fig. 20.—Removing the retainer spring from the end of the piston pin.

Cleaning Engine Parts.—The cleaning of engine parts is divided into two operations:

The first, or degreasing operation, is to remove oil and soft sludge deposits. The second is to remove hard carbon deposits. The first operation facilitates the effectiveness of the second. Caution should be used in the selection and mixing of cleaning compounds since those suitable for cleaning steel parts may be injurious to aluminum or magnesium parts. Care should also be used in determining the length of time the parts are to be submerged in the cleaning solution.

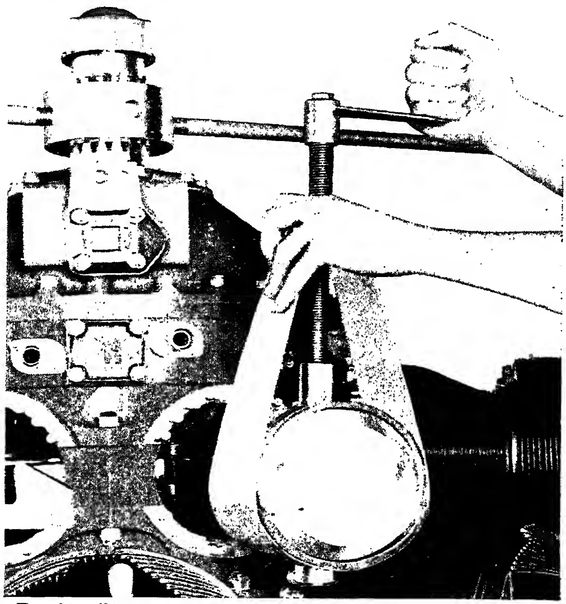


FIG. 21.—Piston pin remover with padded sling to protect piston.

The removal of grease, sludge, and soft carbon deposits may be done by spraying or brushing the parts with gasoline or kerosene under pressure. But owing to the inflammability, expense, and the necessity of having to treat the parts to prevent rusting, many prefer to use other cleaning mediums.

Most water-mixed cleaning solutions have been found unsatisfactory for the reason that should any trace of such solutions, which may contain soap compounds or caustic soda, remain impregnated in the pores of the metal and become mixed with the oil during the operation of the engine, oil foaming might result. In the case of alkaline cleaners, the alkaline compounds combine with the oil in the presence of acids that come from combustive gases and are normally present in the oil and form soap which produces oil foaming.

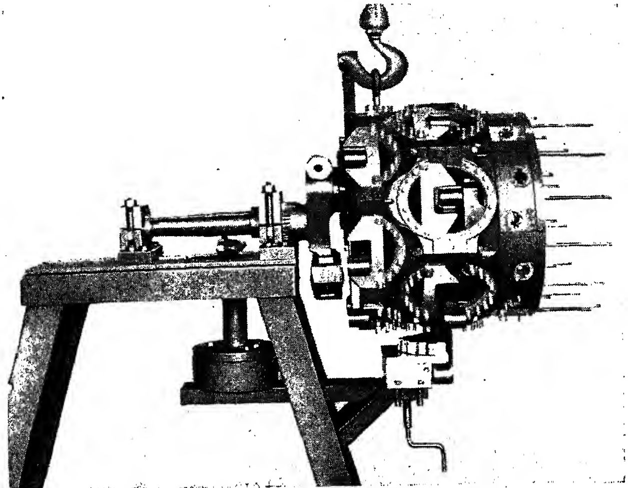


FIG. 22.—Stand for disassembling crankcase parts.

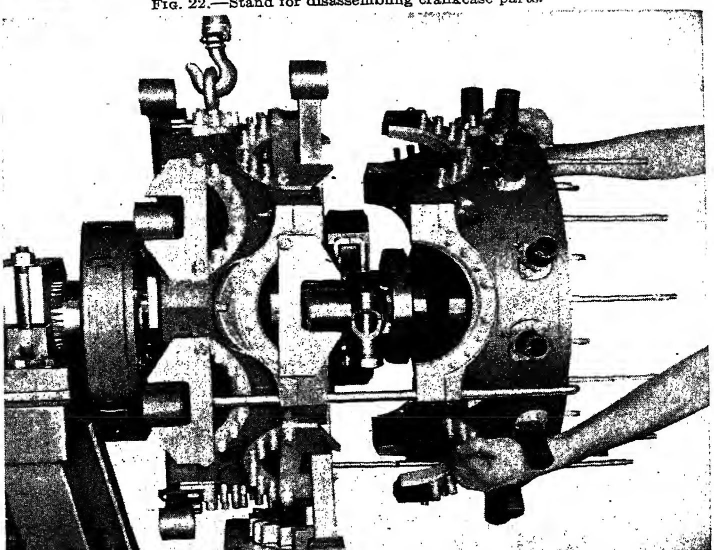


FIG. 23.—These aligning bars help in separating crankcase parts.

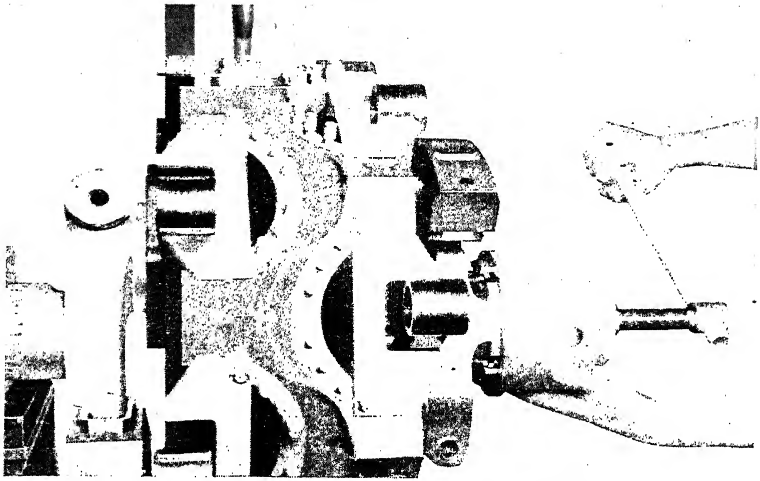


FIG. 24.—Special tool for removing rear main bearing.

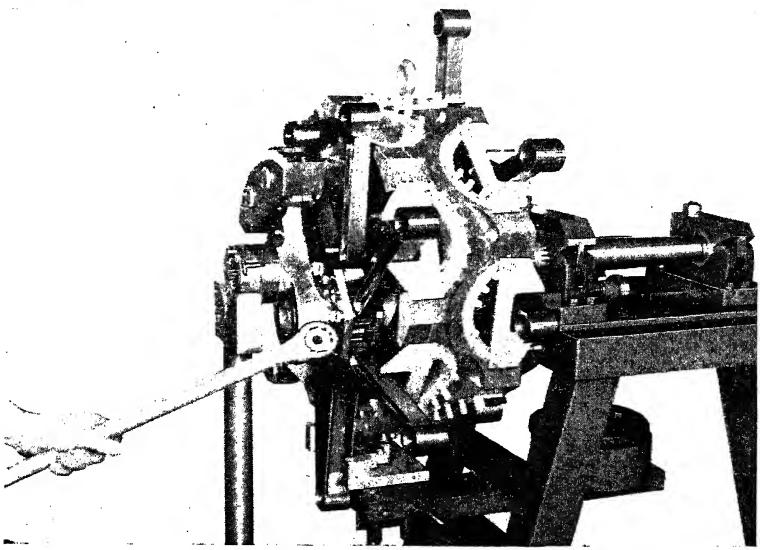


FIG. 25.—Removing rear crankshaft cheek.

The use of cleaning solutions for the removal of hard carbon or tetraethyl lead deposits is not entirely satisfactory. It is recommended that such deposits be removed by hand scraping or some other satisfactory method followed by polishing the part with crocus cloth and gasoline. Gasoline used for cleaning engine parts should be a good grade of ordinary motor gasoline to which *no detonation inhibitors or coloring matter* have been added.

A large variety of cleaning preparations are available but care should be exercised in trying out unfamiliar solutions or compounds, as considerable damage may result, especially to aluminum parts, if allowed to stand in the solution too long.

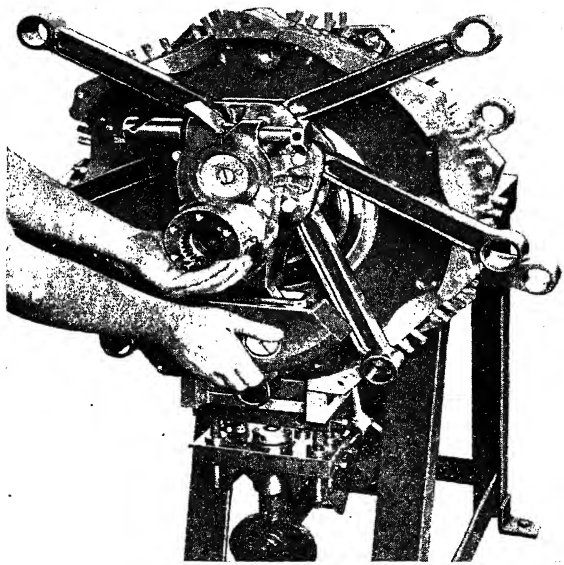


FIG. 26.—Removing the rear section of the crankshaft.

Magnesium parts should be cleaned only with gasoline or kerosene.

Engine parts, except magnesium, may be satisfactorily cleaned as follows: Wash them with Gerlach No. 60 or other suitable degreasing agent. Immerse the parts in Gerlach No. 70 stripper heated to 140°F. Refer to the instructions supplied by the manufacturer of the cleaning solution. The Wright Aeronautical Corp. also issues instructions covering the mixing of these cleaning solutions.

Leave the parts immersed in the solution only long enough to loosen the carbon deposit. Remove the parts from the solution and hand-clean them to remove the loosened deposits; this should be done immediately after removing the parts from the solution to prevent rehardening of the carbon deposits.

Hard carbon may be removed from the pistons or cylinders by either hand scraping or sandblasting. If the carbon is to be removed by hand scraping, care should be exercised to avoid scratching or gouging the parts. Light scraper marks should be removed by polishing with crocus cloth and gasoline. Do not buff the heads of pistons as this procedure may round off the edges at the top ring land. *In no case should the piston bearing surfaces be buffed.*

Removal of carbon from the ring grooves should be done very carefully so as not to remove the small radius between the bottom of each ring groove and the ring land. Use a suitable hand scraper with the sharp corners stoned off so as to preserve the radii in the bottom of the groove.

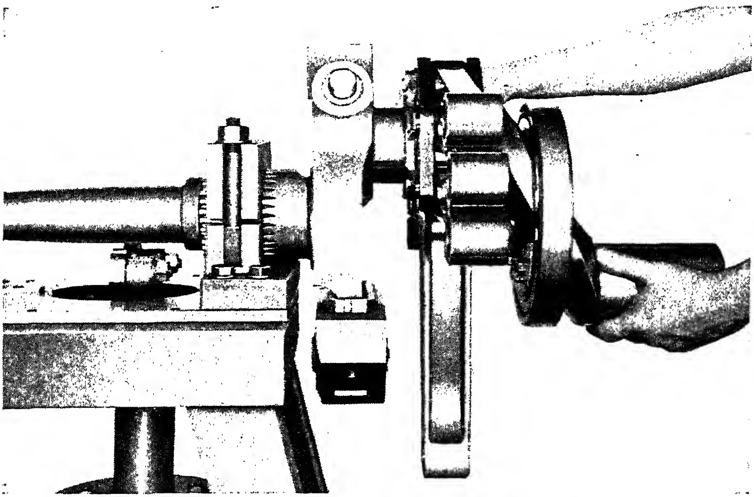


FIG. 27.—Taking out the center section of the crankshaft.

Clean the carbon from the oil drain holes in the ring grooves by using a suitable drill held in a tap handle, being careful not to enlarge or scratch the hole.

If the hard carbon is to be removed by sandblasting, see the suggestions that follow.

Hard carbon and tetraethyl lead deposits, or other foreign material, may readily accumulate in the joint between the cylinder head and the top of the cylinder sleeve. Since special tools have been designed to facilitate cleaning this area, it is recommended that cylinder assemblies be cleaned with them.

To remove material that has become firmly lodged in this joint, a special scraper may be used. It should be held between the thumb and forefinger and drawn around the circumference of the joint, held approximately at right angles to the surface being scraped. In this work, care should be exercised to avoid removing metal or scratching the sleeve.

A special cleaning gun is available for this operation. The gun should be inserted through the flange end of the cylinder sleeve and rotated several times through 360 deg. with the nozzle directed into the joint at the top of the sleeve. The nozzle end should not be used for scraping material from this joint.

The cleaning of the master rods should be done very carefully. Investigation indicates that cleaning solutions have a tendency to remove the lead plate from the surface of the bearings. To prevent the cleaning solution from contacting the bearing surfaces, wipe the master rod bearing clean with a clean cloth saturated with unleaded gasoline or carbon tetrachloride. Do not attempt to clean used bearings by any other means, such as polishing, burnishing, or subjecting them to the action of any cleaning solution other than unleaded gasoline or carbon tetrachloride.

Install plugs in the oil holes in the bearings and protectors, one on each end of the master rod. Degrease and clean the master rod by immersing it in a bath of cleaning solution. Remove the master rod from the cleaning bath. Remove the protectors and oil hole plugs from the rod. Rinse the master rod first in hot and then in cold water to remove all cleaning solution from the rod.

Sandblasting.—The inside of the piston heads may be sandblasted to remove hard carbon. Caution must be exercised in this work to prevent damage to any of the machined surfaces. Prepare the piston for sandblasting as follows: Place a large rubber band in any ring groove in which oil drain holes are located. From the inside of the piston insert a tapered rubber, wood, or fiber plug in each piston pin hole to protect the finished surfaces.

Place the piston in the piston-holding fixture, and use Blastite sandblasting grit, grade No. 30, or other suitable grit.

Steel grit must not be used on the inside of the piston or cylinder heads. Experience shows that particles of grit may become imbedded in the metal. These particles may come loose and circulate with the lubricating oil and result in excessive wear or scoring of internal parts.

Excessive pressure also causes particles of the blasting material to become imbedded in the metal, therefore pressures just high enough to remove the hard carbon should be applied. A properly sandblasted piston should retain a smooth surface. To preserve a smooth finish and prevent impregnating the metal with the blasting material, the following procedure is recommended:

Adjust the air pressure to 15 lb. per sq. in. If the carbon is not satisfactorily removed, increase the pressure in increments of 5 lb. per sq. in. until a pressure is reached that will readily remove the carbon. The amount of pressure necessary will vary from 15 to 30 lb. per sq. in. according to the degree of hardness and amount of carbon to be removed.

Prepare cylinders for sandblasting the combustion chamber by installing the cylinder wall protector sleeve in the cylinder. Install rubber plugs in the valve guide, from the inside. Install dummy spark plugs and washers in each spark-plug insert to protect the insert threads and outer face of the insert. Protect the skirt and flange of the cylinder with a suitable sleeve. To prepare a cylinder for sandblasting the outside surfaces, plug the rocker bolt holes and cylinder mounting flange holes. These plugs should be provided in a form that will ensure protection for the spherical seats at these locations. Insert suitable plugs in the cylinder hold-down flange holes to protect the spherical seats.

Install covers on the rocker boxes. Insert screws or suitable plugs in the cylinder head and intercylinder baffle attaching screw bushings. Put

ENGINE INSPECTION REPORT

Page No. 1 .... Total Time .... Since Overhaul .... Date ....

Engine No. .... Model .... Type .... Work Order No. ....

Part No.	Quan.	Part Name	Remarks	Disposition
		C.C. FRONT SECTION NO.		
		Finished Surfaces—Enamel		
		Oil Passages		
		Retainer—Thr. Brg.		
		Bushings		
		Plugs—Studs—Nuts—Bolts		
		Flange		
		Spacer		
		Plates—Data		
		Oil Drain Tube		
		REDUCTION GEAR		
		Shaft—Propeller No.		
		Threads—splines		
		Journals		
		Oil Passages		
		Bushing—Front		
		Bushing—Rear		
		Bushing—Pinion		
		GEAR STATIONARY NO.		
		Teeth		
		I. D. Oil Passages		
		Ring—Guard		
		Gear—Red. driving		
		Teeth—Splines		
		Nut		
		Pinions		
		Teeth		
		Journals		
		Nuts		
		Ball Brg. Thrust		
		Slinger—Spacer		
		Spacer—Rings		
		Nut—Thrust B. B.		
		Rings		
		Carrier 16:9—16:7		
		Support 16:9—16:7		
		Pinion Bolts 16:9—16:7		
		Pinion Nuts 16:9—16:7		
		Carrier Bolts 16:9—16:7		

Inspected By .... Approved By ....

.... Engine No. ....

FIG. 28.—Suggested form for an inspection report.

plugs in the push rod housing connections and mask the outside surfaces. Put plugs in the intake pipe connections of the rear cylinders and mask the outside surfaces. Mask the exhaust flanges and attaching studs.

Sandblast the cylinder combustion chamber in the manner described for sandblasting the piston heads. Sandblast the valve ports from the inside of the cylinder and through each valve port at the intake and exhaust pipe mounting flanges. Exercise judgment in the matter of removing enamel from the outside of cylinders as it is not always necessary to remove all of the old enamel. After sandblasting, remove all plugs and masking tape from the cylinder.

To sandblast the hard carbon or tetraethyl lead deposits from the exhaust valve heads, install the valve in the holding fixture and sandblast the valve head. Do not sandblast any part of the valve stem during this operation.

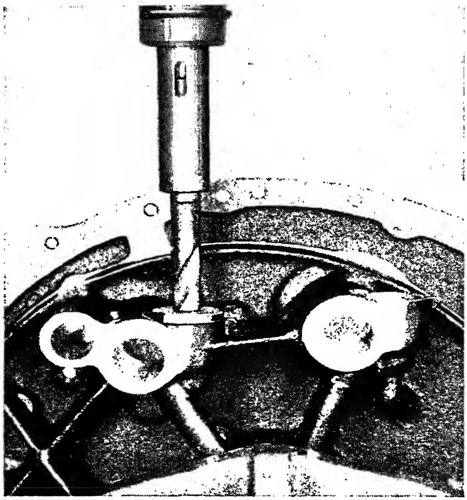


FIG. 29.—Drilling old bushing before removing it.

To ensure systematic inspection and overhaul, the Wright Corp. recommends the use of inspection forms, such as are shown in Fig. 28. Instructions for repair should be entered on these forms which cover the entire engine. The only place where welding of parts is permissible is the air deflectors, where small cracks in either the deflectors or their clamps can be repaired in this way.

Each unit of the engine and its accessories is important and necessary to its proper operation. The reduction gear unit, for example, has a number of parts, including the gearing, that must fit perfectly to give satisfactory service. Special tools are made for removing the pinion gears and special fixtures for boring the propeller shaft bushing where the desired clearance is only 0.002 in.

Fixtures and tools are made by the engine builders for replacing any part liable to wear. A case in point is the magneto drive shaft bushing. Before removing the old bushing the drive *thrust* bushings must be removed as they interfere. When any bushing is removed, the hole should be

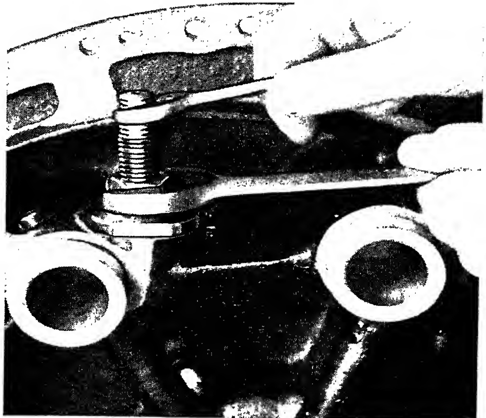


FIG. 30.—Removing the bushing with a threaded puller.

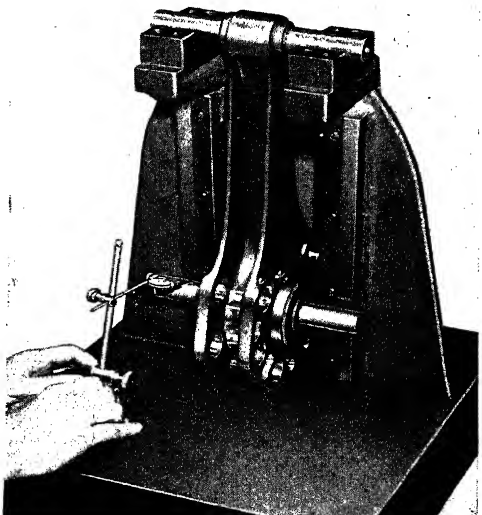


FIG. 31.—Fixture for checking parallelism of holes in a master rod.

inspected as to size, clearness of the oil passages, and condition of the surface. The bushing to be inserted must be checked for size to ensure a proper fit. All bushings should be oiled before being inserted in the holes.

In many cases it is necessary to drill and tap old bushings to remove them easily. Such a case is seen in Fig. 29 where an $^{11}\!/_{16}$-in. hole is being drilled into the bushing so as to use a $^{3}\!/_{4}$-in. tap for pulling it out. This gives only a partial thread but it is plenty for the puller (Fig. 30) to use.

Connecting Rod Work.—Both master and knuckle, or articulated, connecting rods must be handled very carefully. The knuckle pins are removed in an arbor press after removing the locking wires, locking screws, and locking plates. Special wedges are provided to insert between the flanges

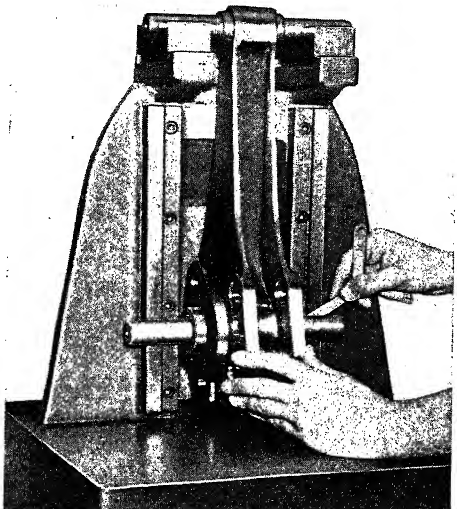


FIG. 32.—Checking "twist" in a master rod.

of the master rod, one on each side of the small rod. It is important that these be used to prevent distortion of the master flanges. Special tools are used to press the knuckle pins out of the small rods.

Alignment of the master rod is checked on the fixture in Figs. 31 and 32. The first check is for parallelism of the two holes. The rod rests on the test bar through the upper hole while the surface gage checks the height of each end of the lower test bar. With the same fixture any twist in the rod is checked by feelers between the ends of the bar and the face of the test fixture. These holes should be parallel within 0.004 in. and at right angles within 0.010 in. Each knuckle-pin hole should also be checked on the same fixture, with a test bar to fit the holes.

Do not attempt to straighten a bent rod, no matter how slight the bend.

The condition and sizes of the holes in the rod must also be checked. Wear allowances are given in Table 1. If the size permits, the holes can

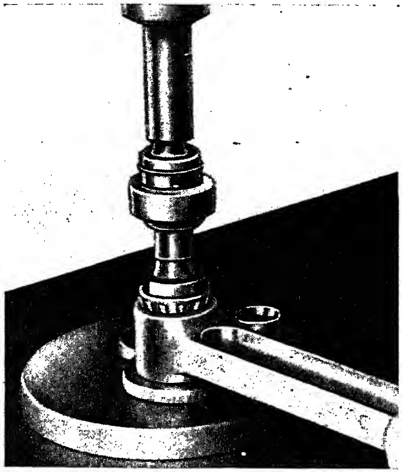


FIG. 33.—Spinning a bushing into the small end of the master rod.

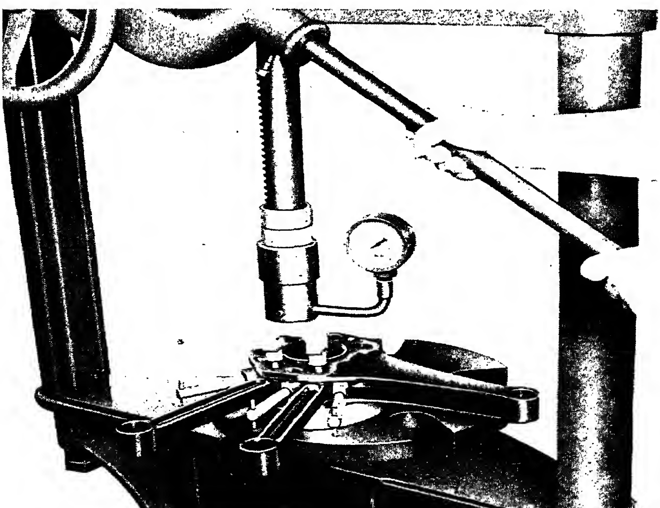


FIG. 34.—Pressing knuckle pins into master and link rods.

be honed. For the master rod bore run the hone at 170 r.p.m. with 80 strokes per min.; for the knuckle-pin holes run the hone 230 r.p.m. with 138 strokes per min. Use honing stones No. 37500H grade for the large hole in steel, and No. 37500DU400 for the small holes. If the holes are chromium plated, use No. 38320I for the master rod and No. MR209FFF-O¾DU400 for the small rods.

The maximum oversize limit of the main bore is 0.010 in. If it cannot be cleaned by grinding out 0.005 in. on a side, the scratch is too deep to be safe.

Bushings are spun into the small end of the master rods and both ends of the articulated rods with the roller tool (Fig. 33). The rod is supported on the base and is centered by a plug in its center.

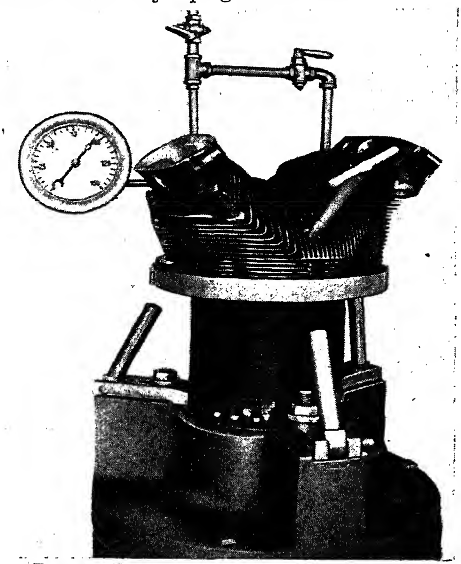


Fig. 35.—Fixture for checking leaks in cylinder.

Knuckle pins are installed in a press, as shown in Fig. 34. Two knuckle pins are inserted loosely in the rods and pressed into place with a measured pressure.

Cylinders are tested for leaks in the fixture in Fig. 35. The cylinders are held by clamps on the flange. The gage shows the pressure that can be maintained in the cylinder.

Gaps in piston rings can best be checked in the cylinder, as in Fig. 36. The ring is placed in the end of the cylinder bore and the piston pulled down against it to square it. The gap can then be easily checked with a feeler gage.

Another interesting operation is installing the intermediate impeller drive shaft and pinion gear assembly, as seen in Fig. 37. This gives a good idea of the gearing and the mechanism in general.

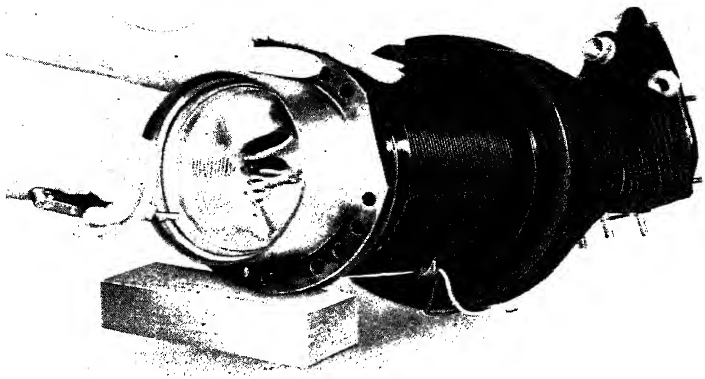


FIG. 36.—Gaps in piston rings are best checked in the cylinder bore.

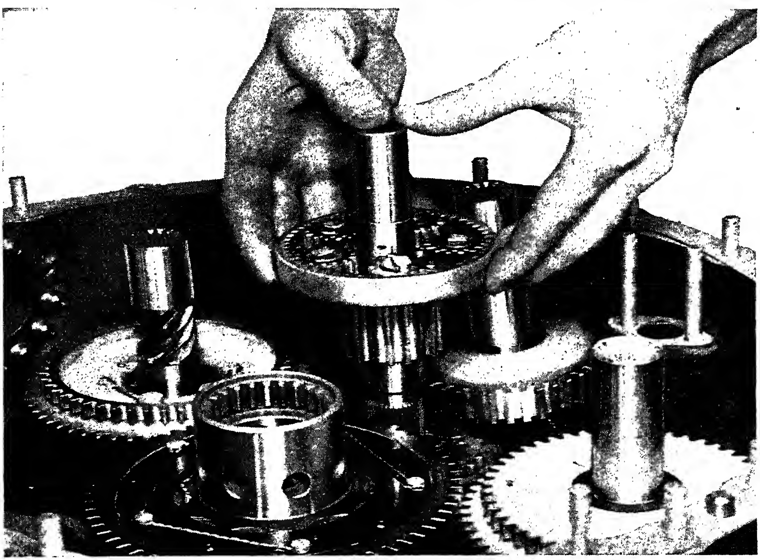


FIG. 37.—Putting an intermediate impeller drive shaft in place.

Stud Replacement.—Two types of cylinder hold-down studs are used in Cyclone 14 engines. Some have a 7/16 in.–20 straight thread on the nut end and a 1/2 in.–11-0.018 in. taper per inch thread on the crankcase end. Some have studs a 7/16 in.–20 straight thread on the nut end and a 1/2 in.-11-0.043 in. taper thread on the crankcase end. The 0.018-in. taper stud can be identified by a 7/16 in. deep conical counterbore in the crankcase end of the stud. The 0.043-in. taper stud is identified by the 90 deg. taper on the crankcase end of the stud.

Oversizes of 0.001 in., 0.003 in., 0.007 in. and 0.012 in. are supplied to replace the standard 0.018-in. tapered stud. These studs may be identified by the marks stamped on the nut end of the studs which correspond to the amount of oversize. One 0.003-in. oversize stud is provided to replace the standard 0.043-in. taper stud. This may be identified by the mark stamped on the chamfer at the crankcase end of the stud.

Careful segregation of all studs is important when these parts are stocked, since the proper selection of a stud to be used as a replacement is essential. An attempt to drive a stud in a crankcase that is not specifically intended for use in that crankcase may cause damage to the stud hole threads and render the crankcase unsatisfactory for use.

Studs are driven to a specified height with a predetermined torque value. These figures must and can be maintained if the drilling and tapping operations are carefully performed and a torque indicator is used with the stud driver. As two variables enter into stud replacement, each individual stud hole should be sized, the proper stud selected, driven into the hole, and the entire work on it completed before proceeding with the replacement of an additional stud or studs.

When cylinder hold-down studs are to be removed, it is desirable to heat the crankcase in a flameless oven, such as an electric oven, at 300 to 350°F. for 1½ to 2 hr. before attempting to remove the studs.

To remove broken 0.018-in. taper cylinder hold-down studs, use a drill jig in the cylinder mounting pad bore with the drill bushing hole over the broken stud. Clamp the drill jig in position. If three adjacent studs are broken or if both studs adjacent to a broken stud have been removed, align the drill jig by sighting through either hole adjacent to the drill bushing hole and clamp the drill jig as previously described.

Successively drill a 1/8-, 1/4-, and 25/64-hole through the stud. Use drill bushings to guide the drills. After drilling, remove the drill jig from the cylinder mounting pad and use a square shank stud remover. Remove the remainder of the stud with a wrench fitted to the square section of the removing tool. Remove all broken studs in the same way.

If the stud requiring replacement is not broken, it may be removed by screwing a stud remover on the nut end of the stud until it is tight. Continue turning the tool in the same direction using short jerks while exerting an even pressure on both handles of the tool, until the stud is seen or felt to move. Then turn the tool in the opposite direction using the same jerking motion on the tool until the stud is free in the crankcase.

Carefully inspect all taps before tapping a stud hole, since rough edges or burrs on the tap may cause it to cut oversize. As new taps usually cut slightly oversize, it is advisable to tap several holes in a test block of the same material as that in which the tap is to be used and make a trial installation of the stud to ensure that proper driving torque and height are obtained. Clean up the stud hole threads in the crankcase before attempting to drive in a new stud.

Table 1.—Limits of Model C14B Cyclone Engine
(For torque values refer to Table 5)

Name	Min., in.	Max., in.
Allowable runout of propeller shaft between threads and splines at forward end when in position in engine.	0.012 max. full indicator reading	
Crankshaft and propeller shaft front bushing, diam.	0.0025L*	0.006L
Propeller shaft and propeller shaft sleeve front, diam.	0.0015T	0.0045T
Propeller shaft front bushing and sleeve, diam.	0.0015T	0.0035T
Allowable runout of crankshaft at front propeller shaft journal when supported at rear propeller shaft journal and center main bearing.	0.006 max. full indicator reading	
Spline, side clearance movement of propeller hub on propeller shaft measured at 15 in. radius from center of propeller shaft.	....	0.040
Propeller shaft, total radial looseness to be measured 1 in. from thrust bearing nut with engine hot. To secure accurate measurement, an indicator must be used.	....	0.015
Propeller shaft thrust bearing spacer and propeller shaft oil seal sleeve, end clearance.	0.006	0.040
Propeller shaft thrust bearing, side clearance.	0.0005T	0.0075L
Propeller shaft thrust bearing and retainer, diam.	0.0014L	0.016L
Propeller shaft and sleeve, diam.	0.0015T	0.0045T
Propeller shaft oil seal sleeve and propeller shaft, diam.	0.0015L	0.003L
Propeller shaft thrust bearing retainer and sleeve, diam.	0.002T	0.004T
Crankshaft and propeller shaft rear bushing, diam.	0.003L	0.008L
Propeller shaft rear bushing and propeller shaft, diam.	0.0015T	0.0045T
Stationary reduction gear bushing and gear, diam.	0.001T	0.005T
Stationary reduction gear and propeller shaft, side clearance.	0.022	0.080
Propeller shaft and reduction gear pinion carrier, diam.	0.001T	0.001L
Reduction gear pinion carrier and bushing, diam.	0.001L	0.006L
Reduction gear pinion and bushing, diam.	0.0025L	0.0035L
Propeller shaft thrust bearing retainer and stationary reduction gear support, diam.	0.001T	0.003L
Crankcase front section and main front crankcase, diam.	0.002T	0.006L
Crankshaft and crankcase main, end clearance.	0.0054L	0.0344L
Allowable runout of crankshaft at front main bearing location when supported at rear proeller shaft journal and main center bearing.	0.006 maximum full indicator reading	
Crankshaft front and rear bearing and crankcase front and rear bearing sleeve, diam.	0.003L	0.0062L
Crankcase and front and rear bearing sleeve, diam.	0.004T	0.006T
Front counterweight and bushing, diam.	0.002L	0.0045L
Front crankshaft and plate and front crankshaft counterweight bushing, diam.	0.001T	0.0025T
Propeller shaft thrust bearing nut oil seal ring gap, hand fit.	0.003	0.006
Propeller shaft thrust bearing nut oil seal ring, side clearance.	0.003L	0.0165L
Propeller shaft oil seal sleeve ring gap, hand fit.	0.009	0.011
Propeller shaft and propeller shaft thrust bearing, diam.	0.0007T	0.0019T
Propeller shaft thrust bearing, total end movement.	0.004	0.0133
Propeller shaft oil seal sleeve ring, side clearance.	0.001L	0.010L
Reduction gear and spacer oil seal ring gap, hand fit.	0.009	0.011
Reduction gear and spacer and oil seal ring, side clearance.	0.001L	0.010
Reduction gear pinion and stationary reduction gear, backlash.	0.011	0.020
Cam drive pinion and cam driving gear, backlash.	0.004	0.020
Reduction gear pinion and reduction driving gear, backlash.	0.011	0.020
Torque indicator booster pump drive gear shaft and bushing, diam.	0.002L	0.005L
Torque indicator booster pump drive gear shaft bushing and crankcase front section, diam.	0.001T	0.003T
Torque indicator booster pump intermediate drive gear and torque indicator booster pump drive gear, backlash.	0.004	0.020
Intermediate cam drive pinion, end clearance.	0.008L	0.015L
Intermediate cam drive gear shaft bracket and sleeve, diam.	0.004T	0.006T
Intermediate cam drive gear shaft bracket and cap—gap when bushings are tight, hand fit.	0.0015L	0.0025L
Intermediate cam drive gear shaft and bushing, diam.	0.0015L	0.008L
Oil supply coupling spring wire, diam. 0.058 to 0.060 in. tension at 1.12 in. height.	7 lb.	
Valve guide support and valve tappet lubrication tube, diam.	0.0005L	0.0025L
Intermediate cam drive gear shaft bracket cap and valve tappet lubrication tube, diam.	0.0005L	0.002L
Cam and cam drive pinion, backlash.	0.006	0.020
Valve tappet guide front support and main crankcase front section, diam.	0.000	0.006L

* The letters L and T mean "loose" and "tight" by the amount shown.

Table 1.—Limits of Model C14B Cyclone Engine (*Continued*)

Name	Min., in.	Max., in.
Crankcase and intermediate cam drive gear shaft bracket, diam.	0.000	0.003L
Cam bearing ring and intake and exhaust cam, diam......	0.003L	0.012L
Cam bearing ring and main crankcase, diam.............	0.003T	0.006T
Crankshaft front end and center cap screw stretch. Use 0.8125 in. diam. ball at head end and 1.000 in. diam. ball at opposite end when measuring stretch..................	0.008	0.0085
Crankshaft and crankshaft front bearing, diam............	0.007T	0.0019T
Crankshaft plates and counterweight front and rear, total side clearance....................................	0.014	0.045
Crankpin length..	3.499	3.503
	(3.500 desired)	
Front and rear crankpin plugs and crankpin, diam.........	0.000	0.0015T
Crankshaft front and rear and crankshaft, diam. before tightening screw....................................	0.002T	0.001L
Master rod bearing and crankshaft, diam. (fit at assembly)...	0.0045L	0.0065L
Master rod bearing and master rod, diam..................	0.0035T	0.0055T
Articulated rod, side clearance...........................	0.007L	0.030L
Knuckle pin and master rod, diam.........................	0.0005T	0.0015T
Knuckle pin bushing and articulated rod, diam.............	0.0045T press fit	
Knuckle pin and bushing, diam............................	0.003L	0.0055L
Main center bearing and support, total side clearance.......	0.0018L	0.0058L
Crankshaft and crankshaft center bearing support, diam. Crankshaft center bearing and center bearing support, diam.	Select to obtain 0.0015T min. fit of bearing considering support thickness when assembled on crankshaft	
Crankshaft center bearing and center bearing sleeve, diam....	0.0025L	0.007L
Crankshaft center bearing sleeve and crankcase, diam........	0.006T	0.010T
Piston pin and piston, diam...............................	0.002L	0.004L
Piston pin and bushing, diam.............................	0.002L	0.0085L
Piston pin bushing and connecting rod, diam................	0.0045T	0.0065T
Piston groove 6 and ring side clearance....................	0.006L	0.008L
Compression and oil scraper piston ring, gap...............	0.032	0.040
Piston groove 5 and ring, side clearance...................	0.011L	0.013L
Piston groove 4 and ring, side clearance...................	0.011L	0.013L
†Piston groove 3 and ring, side clearance (wedge type).......	0.0035L	0.008L
Piston groove 2 and ring, side clearance (wedge type)........	0.0035L	0.008L
Piston groove 1 and ring, side clearance (wedge type)........	0.0035L	0.008L
Piston and cylinder barrel, diam. (center of skirt)...........	0.023L	0.027L
Cylinder barrel bore:		
Wear..		0.010
Out of round...		0.005
Taper..		0.010
Master rod and crankpin, end clearance....................	0.018L	0.040L
Master rod and spacer, diam..............................	0.0005T	0.0025T
Master rod and knuckle pin locking plate, diam.............	0.0005T	0.002L
Crankshaft rear end and center cap screw stretch. Use 0.625 in. diam. ball at head end and 0.750 in. diam. ball at opposite end when measuring stretch..........................	0.008	0.0085
Rear crankshaft and plate and bushing, diam...............	0.001T	0.0025T
Rear counterweight and bushing, diam.....................	0.002L	0.0045L
Valve tappet guide rear support and main crankcase rear section, diam..	0.000	0.006L
Valve tappet and ball socket, diam........................	0.0002L	0.0017L
Valve tappet spring wire, diam. 0.063 in. tension at 2.14 in. height..	10 lb.	
Valve tappet and valve tappet guide (select to obtain)........	0.00175L	0.0035L
Valve tappet guide and support, diam......................	0.000	0.002L
Valve tappet guide and crankcase, diam....................	0.006L	0.012L
Valve tappet roller and bushing, diam.....................	0.001L	0.002L
Valve tappet roller pin and tappet and roller bearing, diam...	0.0025L	0.006L
Crankshaft and crankshaft rear main bearing, diam..........	0.0007T	0.0015T
Crankcase and supercharger front housing, diam............	0.002T	0.006L
Supercharger front housing breather relief valve and seat, diam..	0.004L	0.012L
Supercharger front housing breather relief valve wire, diam. 0.030 in. tension at 0.50 in. height........................	38 lb.	
Allowable runout of crankshaft at rear main bearing location when supported at rear propeller shaft journal and center main bearing.	0.006 full indicator reading	

† Fit obtained when rings are held in contact with a straightedge which, in turn, is held in contact with piston ring lands 2, 3, 4, and 5.

Table 1.—Limits of Model C14B Cyclone Engine (*Continued*)

Name	Min., in.	Max., in.
Cam and cam bearing ring, end clearance	0.006L	0.012L
Rear crankshaft and bushing, diam	0.001T	0.003T
Rear crankshaft bushing and starter and accessory drive shaft, diam	0.001L	0.005L
Starter shaft coupling spring wire, diam. 0.093 in. tension at 0.80 in. height	12.15 lb.	
Rear crankshaft gear oil seal ring, side clearance	0.001L	0.0145L
Rear crankshaft gear oil seal ring gap, hand fit	0.009	0.011
‡Impeller and supercharger front housing, side clearance	0.050L	
Impeller and diffuser plate, side clearance	0.035L	0.045L
Rear crankshaft gear and cam drive pinion, backlash	0.004	0.020
Impeller shaft bearing support and supercharger front housing, diam	0.001L	0.006L
Supercharger front housing and supercharger rear housing, diam	0.0018T	0.004T
Diffuser plate and rear supercharger housing, diam	0.000	0.008L
Impeller drive shaft gear and impeller shaft oil seal front sleeve, diam	0.001L	0.005L
Impeller oil seal ring, side clearance	0.002L	0.030L
Impeller oil seal ring gap, hand fit	0.010	0.0135
Impeller spacer and impeller drive shaft gear, diam	0.001L	0.008L
Starter and accessory drive shaft and front and rear bushing, diam	0.002L	0.006L
Impeller drive shaft gear and front and rear bushing, diam	0.002T	0.004T
Impeller drive shaft gear and rear oil seal sleeve, diam	0.001L	0.005L
Impeller drive shaft gear oil seal rear sleeve ring, side clearance	0.002L	0.030L
Impeller drive shaft gear oil seal rear sleeve ring gap, hand fit	0.010	0.0135
Impeller drive shaft gear, end clearance	0.005L	0.014L
Supercharger rear case and impeller shaft retainer, diam	0.000	0.006L
Supercharger rear case and sleeve, diam	0.001T	0.003T
Impeller shaft drive gear and accessory drive gear and starter and accessory drive shaft, diam	0.001L	0.005L
Impeller shaft oil retainer oil seal ring, side clearance	0.002L	0.030L
Impeller shaft retainer and starter and accessory drive shaft thrust ring, diam	0.002L	0.009L
Starter coupling, locating dimension. After obtaining clearance per next item, machine "spacer V" to obtain this dimension with the starter coupling located in extreme "in" position (forward against accessory shaft, with accessory shaft resting against forward thrust ring)	1.714	1.719
Starter and accessory drive shaft, end clearance, machine at assembly	0.020L	0.030L
Starter and accessory drive shaft bushing and supercharger rear cover, diam	0.005T	0.007T
Starter and accessory drive shaft and bushing, diam	0.002L	0.005L
Impeller drive shaft gear and impeller shaft drive multiplate clutch gear, backlash	0.003	0.018
Starter and accessory drive shaft and starter coupling, diam	0.001L	0.004L
Starter coupling and spacer, diam	0.005L	0.030L
Impeller shaft oil retainer oil seal ring gap, hand fit	0.012	0.0145
Impeller shaft drive multiplate clutch piston 10 to 1 ratio and oil seal ring, side clearance	0.006L	0.015L
Impeller shaft drive multiplate clutch piston oil seal ring 10 to 1 ratio, gap	0.003	0.010
Impeller shaft drive multiplate clutch gear and impeller shaft multiplate piston lug, side clearance	0.035L	0.050L
Supercharger rear case and intermediate impeller drive shaft—propeller end bushing, diam	0.001T	0.004T
Impeller shaft drive multiplate clutch gear 10 to 1 ratio and bushing, diam	0.002L	0.006L
Intermediate impeller drive shaft and impeller drive multiplate clutch gear 10 to 1 ratio, diam	0.001L	0.0045L
Diffuser plate vanes and supercharger front housing	0.002T	0.013T
Impeller shaft drive multiplate clutch disk adapter and ring, diam	0.001T	0.003T
Intermediate impeller drive shaft and oil distributor plug, diam. (front)	0.000	0.0015T
Intermediate impeller drive gear and pinion and drive pinion, backlash	0.004	0.015

‡ See Table 2.

Table 1.—Limits of Model C14B Cyclone Engine (*Continued*)

Name	Min., in.	Max., in.
Impeller drive multiplate clutch sleeve (7.14 to 1 ratio) and supercharger rear cover, diam	0.001L	0.003T
Intermediate impeller drive pinion and bushing, side clearance	0.006L	0.030L
Impeller drive multiplate clutch piston and oil seal ring 7.14 to 1 ratio, side clearance	0.0065L	0.014L
Impeller shaft drive gear and intermediate impeller drive gear and pinion, backlash	0.004	0.018
Impeller drive multiplate clutch piston oil seal ring gap (7.14 to 1 ratio), hand fit	0.003	0.004
Impeller clutch release spring wire, diam. 0.093 in. tension at 0.75 in. height	18 lb.	
Generator gear, end clearance	0.020L	0.060L
Intermediate impeller drive sun gear and two-speed clutch thrust washer lock, diam	0.002L	0.006L
Intermediate impeller sun gear and pinion, backlash	0.004	0.015
Intermediate impeller drive shaft and oil distributor plug, diam. (rear)	0.000	0.002T
Intermediate impeller drive shaft and rear bushing, diam	0.0005L	0.007L
Intermediate impeller drive shaft rear bushing and supercharger rear cover, diam	0.001T	0.003T
Intermediate impeller drive sun gear and bushing, diam	0.002L	0.008L
Intermediate impeller drive shaft and intermediate impeller drive sun gear bushing, diam	0.001L	0.008L
Impeller drive multiplate clutch piston (7.14 to 1 ratio) and intermediate impeller drive shaft rear bushing, diam	0.0005L	0.002L
Generator gear and generator drive oil seal collar, diam	0.0005L	0.004L
Generator drive oil seal spring wire, diam. 0.135 in. tension at 0.50 in. height	9 lb.	
Impeller drive multiplate clutch plate (7.14 to 1 ratio) and housing sleeve, diam	0.011L	0.030L
Intermediate impeller drive pinion and bushing, diam	0.0005L	0.006L
Intermediate impeller drive shaft and intermediate impeller drive pinion bushing, diam	0.0015L	0.007L
Generator gear and bushing, diam	0.003L	0.010L
Generator gear bushing and supercharger rear cover, diam	0.003T	0.005T
Intermediate impeller gear and generator gear, backlash	0.006	0.025
Intermediate impeller drive gear and bushing, diam	0.0025T	0.004T
Intermediate impeller drive shaft and intermediate impeller drive gear bushing, diam	0.001L	0.005L
Intermediate impeller drive shaft plug check valve and oil distributor plug, diam	0.002L	0.012L
Generator gear and plug, diam	0.001T	0.003T
Impeller clutch release spring wire, diam. 0.105 in. tension at 0.50 in. height	16.74 lb.	
Intermediate impeller drive shaft and piston (10 to 1 ratio), diam	0.001L	0.006L
Intermediate impeller drive shaft plug check valve spring wire, diam. 0.020 in. tension at 0.50 in. height	225 lb.	
Torque arm and bushing button, diam	0.0015T	0.004T
Torque arm and torque indicator over running-valve, diam	0.001L	0.007L
Torque indicator housing and valve housing, diam	0.001T	0.003T
Torque indicator valve oil seal ring, gap	0.002L	0.008L
Torque indicator valve housing and oil seal ring, side clearance	0.002L	0.010L
Torque indicator valve housing and sleeve, diam	0.002T	0.004T
Torque indicator housing and valve housing, diam	0.001T	0.003T
Crankcase front section and torque indicator housing, side clearance	0.004L	0.002T
Governor adapter and torque indicator booster pump cover and drive gear, diam	0.001L	0.005L
Governor adapter and governor drive gear, diam	0.001L	0.005L
Governor drive gear and torque indicator gear, backlash	0.004L	0.016L
Governor adapter and governor drive gear and torque indicator gear, side clearance	0.003L	0.0075L
Governor drive gear and governor adapter, diam	0.001L	0.005L
Governor drive gear and bushing, diam	0.001L	0.005L
Governor adapter and governor drive gear and bushing, diam	0.001T	0.003T
Governor adapter and crankcase front section, diam	0.001L	0.005L
Torque indicator booster pump housing and cover and torque indicator drive gear, diam	0.001L	0.005L
Torque arm support and propeller shaft thrust bearing retainer and sleeve, diam	0.002T	0.004T

Table 1.—Limits of Model C14B Cyclone Engine *(Continued)*

Name	Min., in.	Max., in.
Governor drive gear and torque indicator booster pump housing gear cage, diam	0.004L	0.010L
Torque indicator gear and torque indicator booster pump housing gear cage, diam	0.004L	0.010L
Torque indicator booster pump housing and crankcase front section, diam	0.001L	0.005L
Oil strainer and supercharger rear cover, diam	0.0025L	0.000
Valve tappet guide support (rear) and tube, diam	0.0005L	0.003L
Valve tappet guide support oil tube (rear) spring wire, diam. 0.070 in.–0.072 in. Tension at 3.84 in. height	7.65 lb.	
Valve tappet guide support (rear) large and small tube, diam	0.0005L	0.003L
Oil pump drive gear bushing and supercharger rear cover, diam.	0.001T	0.003T
Oil pump drive gear and bushing, diam	0.001L	0.008L
Oil pump drive gear, end clearance	0.020L	0.063L
Oil pump drive shaft and end plate, diam	0.0015L	0.015L
Oil pump suction idler gear shaft and end plate, diam	0.0005T	0.0025L
Oil pump suction idler gear and drive shaft (gear) and body, diam	0.001L	0.010L
Oil pump suction idler gear shaft and gear, diam	0.0015L	0.008L
Oil pump body and clutch control valve shaft end bushing, diam	0.000	0.0025L
Oil pump body and clutch control valve shaft, diam	0.0005L	0.004L
Clutch control valve shaft and plug, diam	0.003L	0.009L
Clutch control valve shaft and pinion, diam	0.0005T	0.0025T
Clutch control valve and pinion, diam	0.0005L	0.005L
Clutch control valve seat and oil pump body, diam	0.000	0.003L
Clutch control valve shaft torque and valve slot, side clearance	0.002L	0.008L
Clutch control valve and retainer, diam	0.0005L	0.004L
Clutch control valve spring wire, diam. 0.063 in. Tension at 2.00 in. height	7.76 lb.	
Clutch control valve and bushing, diam	0.0005L	0.0035L
Clutch control valve bushing and oil pump body, diam	0.001T	0.003T
Clutch control valve stop spring wire, diam. 0.046 in. Tension at 0.563 in. height	8.1 lb.	
Oil pressure relief valve body and oil pump body, diam	0.000	0.005L
Oil pump drive shaft (gear) and idler gear and oil pump body, end clearance	0.0025L	0.013L
Oil pressure relief valve and body, diam	0.0025L	0.005L
Oil pressure relief valve spring wire, diam. 0.071 in. Tension at 1.40 in. height	19 lb.	
Oil pump body and idler gear shaft, diam	0.001T	0.0025T
Oil pump suction idler gear and oil pump drive shaft, backlash.	0.004	0.020
Oil pressure pump idler gear and oil pump body, diam	0.002L	0.015L
Oil pump suction body and oil pump body and oil pressure pump drive gear, diam	0.002L	0.015L
Oil pressure pump drive gear and idler gear and oil pump body gear gage, diam	0.001L	0.0105L
Oil pump drive shaft and oil pressure pump drive gear, diam	0.0005L	0.0035L
Oil pump suction body and oil pressure pump idler gear, diam.	0.002L	0.015L
Oil pressure pump drive gear and idler gear, backlash	0.004	0.020
Oil pressure pump drive gear and idler gear and oil pump body, end clearance	0.0035L	0.013L
Oil pump suction drive gear and oil pump suction body and oil pump cover, diam	0.002L	0.015L
Oil pump suction drive gear and idler gear and oil pump suction body, end clearance	0.0035L	0.013L
Oil pump suction idler gear shaft and oil pump suction body, diam	0.0005T	0.0025T
Oil pump suction drive gear and oil pump suction idler gear, backlash	0.004	0.020
Oil pump suction idler gear and oil pump cover, diam	0.0005T	0.0025L
Oil pump drive shaft and plug, diam	0.001T	0.003T
Oil pump check valve body and oil pump body, diam	0.0005T	0.0025T
Oil pump check valve and ring, side clearance	0.002L	0.010L
Oil pump check valve ring, gap	0.003	0.012
Oil pump check valve spring wire, diam. 0.063 in. Tension at 2.00 in. height	7.76 lb.	
Front supercharger housing and dowel to rear guide support, diam	0.002T	0.000
Accessory drive intermediate gear and magneto drive gear, backlash	0.004	0.025
Accessory drive gear and accessory intermediate drive gear, backlash	0.004	0.025

Table 1.—Limits of Model C14B Cyclone Engine (*Continued*)

Name	Min., in.	Max., in.
Oil sump relief check valve spring wire, diam. 0.063 in. Tension at 2.92 in. height	6.3 lb.	
Oil sump and oil sump check relief valve seat, diam	0.0015T	0.0035T
Tachometer drive shaft and bushing, diam	0.001L	0.008L
Tachometer drive shaft bushing and support, diam	0.001T	0.003T
Tachometer drive shaft support and supercharger rear cover, diam	0.000	0.003L
Fuel pump and tachometer drive housing and support, diam	0.000	0.005L
Tachometer drive packing gland spring tension wire, diam. 0.095 in. Tension at 0.60 in. height	16 lb.	
Fuel pump and tachometer drive housing and tachometer drive gear shaft bushing, diam	0.001L	0.003L
Fuel pump and tachometer drive housing and tachometer drive gear shaft bushing, diam	0.001L	0.003L
Tachometer drive gear shaft and bushing, diam	0.0035L	0.0095L
Tachometer and fuel pump drive shaft and tachometer drive gear shaft, backlash	0.004	0.025
Tachometer drive gear shaft and bearing, end clearance	0.003L	0.040L
Magneto and gun synchronizer drive shaft and bushing, diam.	0.001L	0.008L
Magneto and gun synchronizer drive shaft bushing and supercharger rear cover, diam	0.001T	0.003T
Magneto packing retaining ring and rear cover, diam	0.005L	0.012L
Rocker arm bearing and rocker arm, diam	0.0008T	0.0018T
Rocker roller hub and rocker arm, side clearance	Rivet tight	
Rocker roller hub and rocker roller, diam	0.0015L	0.020L
Rocker roller hub and pin, diam	0.001T	0.002T
Rocker roller and rocker arm, side clearance	0.0095L	0.050L
Rocker bolt and rocker arm bearing, diam	0.000	0.004L
Rocker arm bearing and rocker box bolt bushing (side clearance before clamping)	0.001L	0.015L
Rocker bolt and rocker box bolt bushing, diam	0.0005L	0.005L
Cylinder head and rocker box bolt bushing, diam	0.0009T	0.0024T
†Valve spring tension		
Valve guide and cylinder head, diam.:		
Intake	0.001T	0.003T
Exhaust	0.003T	0.0045T
Valve guide and valve, diam.:		
Intake	0.002L	0.008L
Exhaust	0.0035L	0.008L
Valve seat and cylinder head, diam.:		
Intake	0.0095T	0.135T
Exhaust	0.0095T	0.135T
Fuel pump and tachometer drive housing and tachometer drive gear shaft bearing, diam	0.0005T	0.0035T
Tachometer drive gear shaft and plug, diam	0.001T	0.003T
Tachometer drive gear shaft and collar, diam	0.0005T	0.002T
Magneto and gun synchronizer drive shaft and thrust plug, diam	0.001T	0.003T
Fuel pump, tachometer, and spare drive shaft and thrust plug, diam	0.001T	0.003T
Tachometer, fuel pump, and spare drive shaft and rear supercharger housing, end clearance	0.003	0.032
Magneto and gun synchronizer drive shaft and rear supercharger housing, end clearance	0.003	0.040
Fuel pump—tachometer and spare drive shaft and bushing, diam	0.001L	0.008L
Fuel pump—tachometer and spare drive shaft bushing and supercharger rear cover, diam	0.001T	0.003T
Oil pump drive gear spring wire, diam. 0.080 in. Tension at 2.88 in. height	8 lb.	
Magneto and gun synchronizer drive shaft and fuel pump and tachometer drive shaft, backlash	0.004	0.025
Magneto drive oil seal spring wire, diam. 0.091 in. Tension at 0.36 in. height	9 lb.	
Intermediate impeller drive shaft, end play	0.016L	
Impeller shaft drive gear and impeller shaft drive multiplate clutch gear, clearance	0.016L	

† Refer to Table 2.

Table 2.—Valve Spring Tension

Spring	Wire diam., in.	At height, in.	Tension, lb.
Inner	0.133–0.137	1.438	52.25
Inner	0.133–0.137	2.000	32.40
Intermediate	0.160–0.164	1.531	71.25
Intermediate	0.160–0.164	2.094	48.60
Outer	0.190–0.194	1.406	95.00
Outer	0.190–0.194	1.969	63.90

Table 3.—Limits of Model C14A Cyclone Engine
(For torque values refer to Table 5)

Name	Min., in.	Max., in.
Accessory drive and starter shaft and coupling, diam	0.0015L*	0.004L
Supercharger front housing sleeve and housing, diam	0.0005T	0.0025T
Impeller shaft front and rear sleeve oil seal ring, side clearance	0.002L	0.030L
Impeller shaft front and rear sleeve oil seal ring, gap hand fit	0.010	0.0135
Accessory drive and starter shaft and impeller drive shaft front bushing, diam	0.0025L	0.006L
Impeller drive shaft front and rear bushing and shaft, diam	0.002T	0.004T
Involute spline impeller and impeller shaft	0.000	0.0023T
†Impeller and impeller shroud plate, side clearance	0.035L	0.045L
Impeller and diffuser plate, side clearance	0.050L	
Impeller shroud plate and rear supercharger housing, diam	0.000	0.008L
Supercharger rear housing and front housing, diam	0.002T	0.006L
Impeller drive shaft gear, end clearance	0.005L	0.014L
Accessory drive and starter shaft and impeller drive shaft rear bushing, diam	0.0025L	0.006L
Impeller shaft retainer oil seal ring, gap hand fit	0.012	0.0135
Impeller shaft retainer and ring, side clearance	0.002L	0.030L
‡Starter coupling, locating dimension	1.714	1.719
Accessory drive and starter shaft, side clearance machine at assembly	0.020L	0.040L
Starter shaft bushing and supercharger rear cover	0.003T	0.007T
Accessory drive and starter shaft and accessory drive and starter shaft bushing, diam	0.002L	0.006L
Supercharger rear housing sleeve and housing, diam	0.001L	0.003T
Accessory drive gear spring wire, diam. 0.225 in. Tension at 1.544 in. height	0.550 lb.	
Accessory drive and starter shaft and starter coupling, diam	0.001L	0.004L
Starter coupling and spacer, diam	0.005L	0.030L
Intermediate impeller drive shaft propeller end bushing and supercharger rear housing, diam	0.001T	0.004T
Supercharger intermediate gear shaft and intermediate impeller drive shaft propeller end bushing, diam	0.0005L	0.006L
Supercharger rear cover and impeller drive shaft bushing, diam	0.001T	0.003T
Intermediate impeller drive shaft and rear bushing, diam	0.0005L	0.007L
Supercharger intermediate gear shaft, end clearance	0.023L	0.065L
Impeller drive shaft gear and intermediate gear shaft, backlash	0.004	0.018
Intermediate supercharger gear shaft and accessory drive gear, backlash	0.006	0.020
Generator gear bushing and supercharger rear cover, diam	0.0015T	0.0035T
Generator gear and bushing, diam	0.001L	0.008L
Generator gear oil seal spring, wire diam. 0.027 in. Tension at 0.94 in. height	9 lb.	
Generator gear spring retainer and pin, diam	0.002L	0.008L
Generator gear and spring retainer, diam	0.003L	0.008L
Intermediate impeller drive gear and pinion and generator gear, backlash	0.006	0.025
Generator gear and generator drive oil seal collar, diam	0.000	0.0015T

* The letters L and T mean "loose" and "tight" by the amount shown.
† This clearance to be maintained at all points of impeller circumference.
‡ After obtaining clearance per next item, machine "spacer K" to obtain this dimension with the starter coupling located in extreme "in" position (forward against accessory shaft with accessory shaft resting against forward thrust ring).

Table 4.—Limits of Model C14A Cyclone Engine
(For torque values refer to Table 5)

Name	Min., in.	Max. in.
Accessory drive intermediate shaft and bushing, diam	0.001L*	0.005L
Accessory drive intermediate shaft gear and bushing, diam	0.001L	0.005L
Accessory drive shaft, end clearance	0.009L	0.025L
Accessory drive shaft sleeve and bushing, diam	0.002L	0.006L
Accessory drive shaft, end clearance	0.007L	0.025L
Vacuum pump shaft and accessory drive shaft spline, side clearance	0.001L	0.010L
Accessory drive shaft and accessory drive intermediate shaft gear, backlash	0.004	0.020
Accessory drive idler gear and bushing, diam	0.002L	0.008L
Accessory drive idler gear, end clearance	0.006L	0.040L
Accessory drive idler gear bushing, diam	0.001T	0.003T
Accessory intermediate gear and intermediate shaft gear, backlash	0.004	0.020
Accessory drive intermediate shaft and bushing, diam	0.002L	0.008L
Accessory drive intermediate shaft, end clearance	0.006L	0.040L
Accessory drive intermediate shaft bushing, diam	0.001T	0.003T
Upper vacuum pump drive gear and bushing, diam	0.002L	0.008L
Upper vacuum pump drive gear, end clearance	0.014L	0.050L
Upper vacuum pump drive gear bushing, diam	0.001T	0.003T
Accessory drive idler gear and upper and lower vacuum pump drive gears, backlash	0.004	0.020
Lower vacuum pump drive gear and front bushing, diam	0.002L	0.008L
Lower vacuum pump drive gear and rear bushing, diam	0.004L	0.010L
Lower vacuum pump drive gear, end clearance	0.011L	0.050L
Lower vacuum pump drive gear front bushing and housing, diam	0.001T	0.003T
Lower vacuum pump drive gear rear bushing and cover, diam	0.002T	0.004T
†Upper vacuum pump drive gear bushing, diam. (rear)	0.002T	0.004T
†Upper vacuum pump drive gear and bushing, diam. (rear)	0.004L	0.010L
‡Upper vacuum pump drive gear, end clearance	0.011L	0.050L

* The letters L and T mean "loose" and "tight" by the amount shown.
† For involute coupling drive (standard and special ratio accessory drive shafts).
‡ For special accessory drive shaft with a ratio of 1.636 to 1.

Table 5.—Tightening Torque Values for All Models of Cyclone 14 Engines
(Standard studs, bolts, screws, and cap screws)

Name	Size of thread nut end	Min. Diam. of thread root or neck, in.	Min., Rockwell hardness	Torque values, in.-lb. Driving stud Min.	Torque values, in.-lb. Driving stud Max.	Torque values, in.-lb. Tightening nut, screw, or cap screw Min.	Torque values, in.-lb. Tightening nut, screw, or cap screw Max.
Buttonhead screw	10-32	0.1467	B-50	.....	.....	20	25
	12-24	0.1585	B-50	.....	.....	25	30
Studs, bolts, screws and cap screws	10-32	0.1467	C-19	.....	.....	35	40
	12-24	0.1585	C-19	.....	.....	45	50
	1/4-28	0.1800	C-26	50	70	80	85
	5/16-24	0.2290	C-26	100	150	160	175
	3/8-24	0.2850	C-26	200	275	225	250
	7/16-20	0.3310	C-26	300	425	350	375
	1/2-20	0.3870	C-26	500	700	550	600
	9/16-18	0.4360	C-26	750	975	825	875
	5/8-18	0.4930	C-26	1,100	1,400	1,125	1,200
Standard Practices for Special Applications							
Cylinder hold-down stud		0.3130	C-32	325	450	350	375
Cylinder hold-down cap screw		0.3300	C-26			375	400
Cylinder hold-down stud		0.3310	C-32	400	550	425	450
Rocker hub bolt		0.3710	C-32			250	325
		0.4000	C-19			250	325
Spark plug	[illegible]16-18	0.4880	C-26			300	375
	[illegible] mm.					450	500

If it is necessary to replace either of the two studs located directly above the intercrankcase oil tube fittings, exercise care when drilling the stud or tapping the stud hole threads to avoid striking these fittings or the heads of the plugs installed in these fittings.

Some of the cylinder hold-down stud holes are not drilled through the crankcase. In replacing broken studs in these locations, exercise care when drilling the stud to avoid drilling into the crankcase. When tapping the stud holes in these locations, do not allow the end of the tap to bottom against the crankcase.

To prevent oil leakage around the root of the thread a sealing agent is used on the threads. Glyptal is recommended for this purpose. Clean

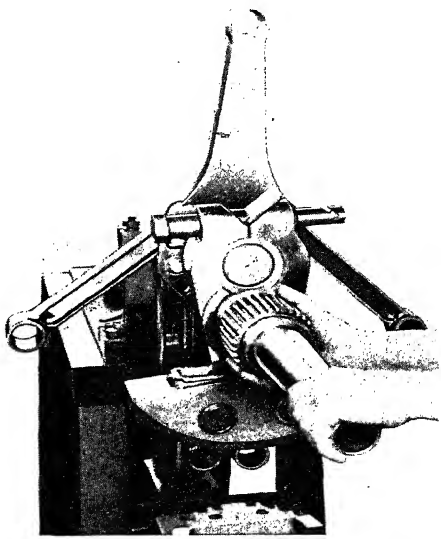


FIG. 38.—Putting the front section of the crankshaft in place.

the stud hole and threads in the crankcase thoroughly with alcohol or Glyptal thinner and apply a thin coat of Glyptal to the lower threads of the holes that are drilled through the crankcase. No Glyptal is necessary on the threads in the stud holes that are not drilled through the crankcase. To apply the Glyptal to the threads, use a piece of twisted wire or a toothpick. Dip the end of the wire or toothpick in the Glyptal, insert the applicator in the stud hole from the top of the hole, and apply the Glyptal evenly around the third or fourth thread from the bottom of the stud hole. Apply a thin coating of Bestolife to all except the first or leading thread on the new stud and insert the stud.

The following suggestions will assist the operator in becoming familiar with the proper stud installation procedure:

After preparing the stud hole to receive a new stud, select a standard stud and drive it in using a torque of 400 in.-lb. Measure the height of the stud and, if it is at the high limit of 0.960 in., reapply the stud driver and drive in the stud, applying a torque of 500 in.-lb. Again measure the height of the stud. If the measurement falls within the specified height limits, the stud is satisfactory. If not, remove the stud and retap the threads in the crankcase, setting the tap to cut 0.020 in. deeper than the previous setting. Install the stud and repeat the procedure.

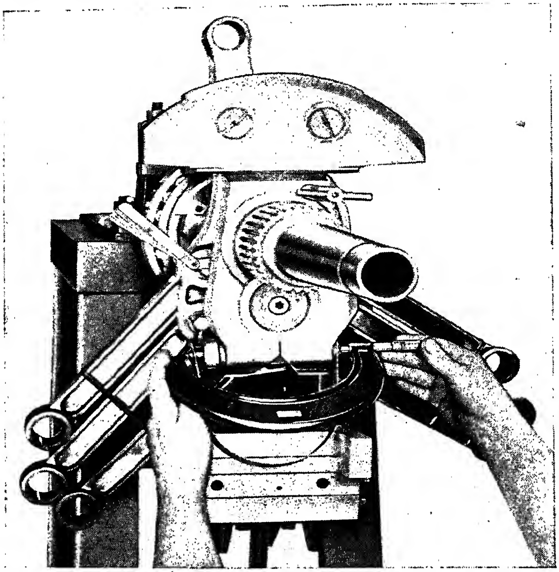


FIG. 39.—Measuring the stretch of a bolt due to tightening.

If the height of the stud is less than 0.900 in. when a torque of 400 in.-lb. is applied, remove the stud, install the next oversize stud, and repeat the procedure.

Reassembly Crankshaft.—The front section of the crankshaft is installed in the fixture shown in Fig. 38. Clean the bore of the clamp joint and spread just enough to let the crankpin slide in easily. In clamping the pin in place it is necessary to measure the stretch of the cap screw. Put the cap screw in place but do not tighten it. Measure it (Fig. 39) with a micrometer over two balls held against the cap screw center by a spring. Apply the wrench (Fig. 40) and note the amount of stretch due to tightening. The desired stretch is found in Table 1. It is 0.008 to 0.0085 in.

Alignment of the crankshaft is checked as in Fig. 41 where the indicator is at the front end of the shaft. This is repeated at the other end in a similar manner; Fig. 42 shows the use of a torque indicating wrench. It is being used to tighten the rocker arm hub bolt.

An excellent type of engine stand is seen in Fig. 43. The engine is suspended so as to be accessible on all sides and can readily be moved to any desired place with ease and safety. This is used in slushing valve stems and guides, using the air-driven starter.

Timing the Magneto.—Before installing the magnetos be sure the magneto cam follower felt is not lodged between the fiber cam follower block and the cam.

Turn the magneto drive shaft in the direction of rotation until the timing mark *A* (Fig. 44) on the distributor rotor lines up with mark *B* on the magneto front end plate.

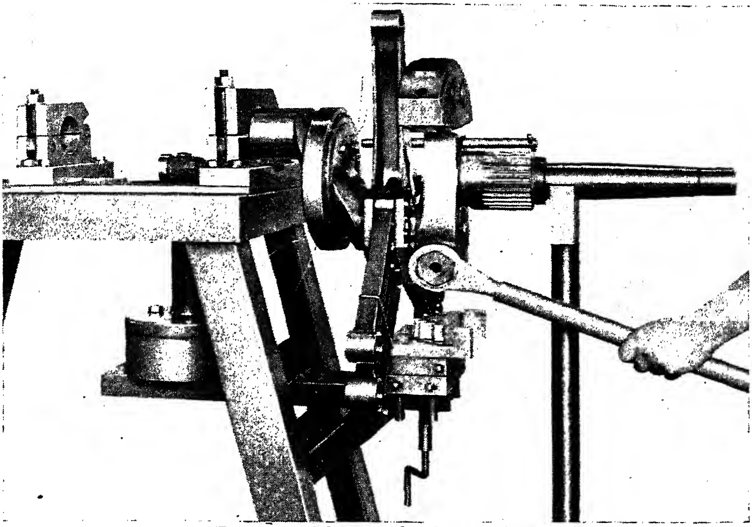


Fig. 40.—Tightening the clamping bolt.

Place a 6-in. steel scale *K* against the face of the step cut in the cam *L*. Turn the magneto drive shaft slightly until this straightedge coincides with the lines *M* cut in the rim of the breaker housing. In this position the breaker contacts should just be opening.

Pivotless breakers must always be adjusted so that the contacts open at the proper position of the cam and not for any fixed clearance between the contact points.

If inspection shows that the position of opening of the contacts requires adjustment, loosen the two screws *O*, which fasten the breaker support to the breaker housing. Hold the cam in position to open the contacts as indicated by the straightedge and adjust by means of the eccentric screw *P* until the contacts are just opening. Secure them in this position by tightening the screws *O*.

The position of the opening can be checked by inserting a 0.001-in. feeler between the contact points *C* by lifting the felt-covered cam follower *F*

which causes the points to open. Do not open the points by lifting the breaker spring *G* as a permanent set in the spring may result from bending at the spring pivot.

A better method is to turn the magneto shaft in the direction of rotation until the breaker points are opened by the cam. Insert the feeler gage, turn the magneto shaft in the opposite direction of rotation until the feeler gage is tight, then turn the shaft slowly in the direction of rotation until the feeler gage just begins to loosen, indicating that the breaker points are

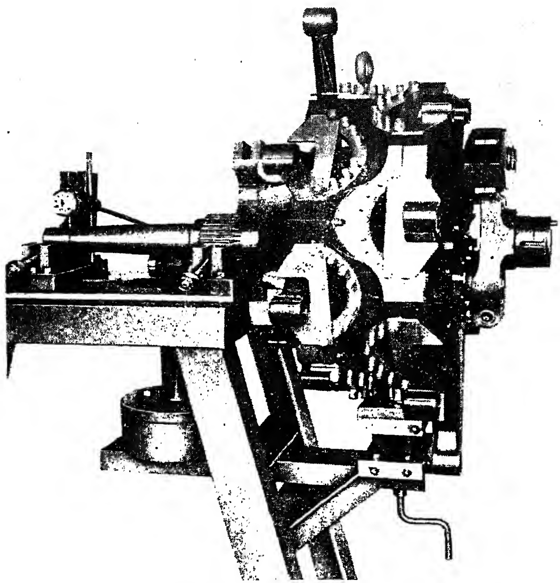


FIG. 41.—Checking alignment of crankshaft after reassembly.

beginning to open. Place the straightedge against the face of the step in the cam and check the alignment with the marks *M* in the rim of the breaker housing.

If the straightedge does not coincide with the timing marks, turn the magneto shaft slightly until the alignment is made, keeping the 0.001-in. feeler between the points. Loosen the two screws *O* which fasten the breaker assembly to the breaker housing. Hold the magneto shaft in aligned position and adjust the eccentric screw *P*, so that the contact points are just beginning to open. Tighten the securing screws *O* and recheck the adjustment.

Install the timing disk with adapter on engines equipped with non-detachable starter dog and the same timing disk with the proper adapter

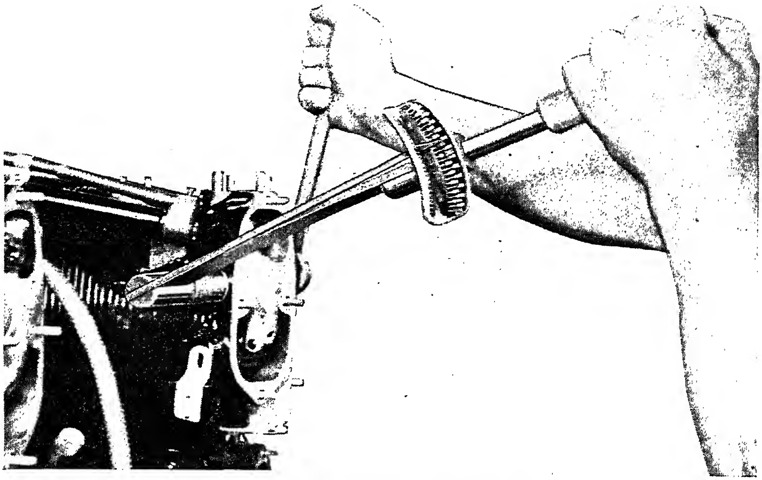


FIG. 42.—Using a wrench that indicates torque.

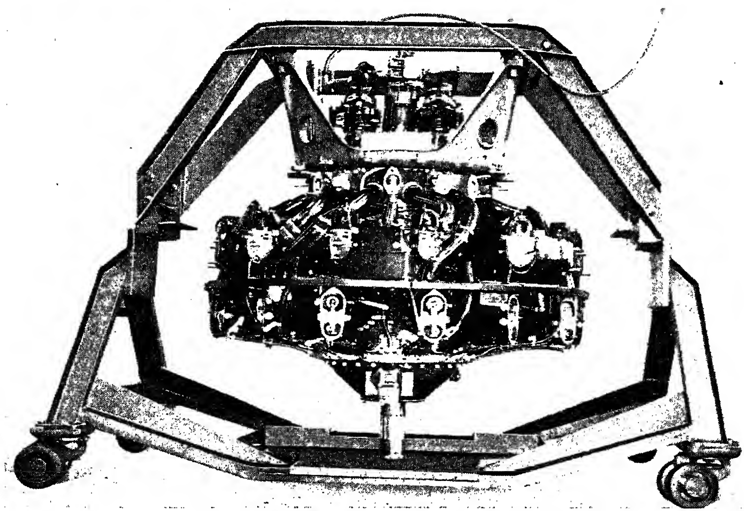


FIG. 43.—An excellent type of engine-assembling stand.

on engines equipped with detachable three-jaw starter dog on the starter mounting pad and secure it with regular starter attaching nuts.

Install a top center indicator in the front spark-plug insert of cylinder 1. These tools should always be available at overhaul stations.

Install the propeller shaft turning hub and note the top center indicator pointer when the crankshaft is turned to determine if the pointer arm is contacting the piston properly. This may be determined by slowly turning the crankshaft until the piston nears the top center position and contacts the pointer arm. If the pointer arm is properly adjusted, the pointer will rise a few graduations as the piston approaches its top center position, pause for a moment, and then return to its original position as the piston moves on its downward stroke. If the pointer moves upward off the graduated scale as the piston approaches top center, reverse the crankshaft rotation, remove the top center indicator, and readjust the angle of the pointer arm in an upward direction. If the arm does not move, adjust it in a downward position. Repeat this procedure until the top center indicator is adjusted to register properly.

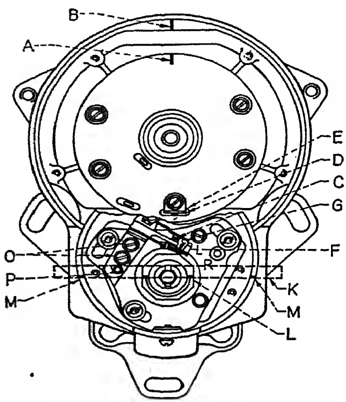


FIG. 44.—Checking the magneto before installing.

Adjust the pointer on the timing disk to read zero when the top center indicator shows the piston in cylinder 1 to be on the top center of its compression stroke. This may be checked as follows: Turn the crankshaft in the direction of rotation until the pointer on the top center indicator is in the middle of the graduated scale. Note the reading in degrees indicated by the pointer on the timing disk.

Continue to turn the crankshaft until the pointer on the top center indicator has completed its upward stroke and return to the point at which the first reading was taken. Again note the reading in degrees indicated by the timing disk pointer.

The exact top center position is the point midway between the two timing disk readings.

Turn the crankshaft in the opposite direction of rotation for approximately one-quarter turn, then turn it forward to the point midway between the two readings previously obtained, and adjust the zero mark on the timing disk to coincide with the pointer.

Remove the top center indicator from cylinder 1 and put in the vented dummy spark plug.

Inspect the front face of each magneto mounting flange to make sure the leather plugs are in position in the four cap-screw head recesses and that they are below the mounting flange surface.

Coat the splines of each magneto drive shaft coupling with vaseline and place a gasket on each mounting pad.

Turn the crankshaft in the opposite direction of rotation one-quarter turn, then bring it forward until the timing disk pointer indicates the proper

timing position for the magneto to be installed. Refer to the engine data plate for the correct magneto timing values.

The magneto timing on some engines is staggered and it is advisable to install the magneto having the greatest amount of advance first.

Turn the magneto drive shaft until the timing mark *A* on the distributor rotor lines up with the mark *B* on the front end plate. Hold the distributor gears in this position and mount the magneto on the engine. Oscillate the magneto the full length of the slots and note if the breaker points open and close. If the breaker points open and close, install the flat washers and castellated nuts on each of the attaching studs sufficiently tight to support the magneto firmly on the cover but not tight enough to prevent adjusting the position of the magneto. If the points do not open and close when moving the magneto in its slots, withdraw it from the engine, reset the distributor rotor, and replace the magneto, engaging the splined magneto coupling in a spline on either side of the original one.

Recheck the opening and closing of the breaker points by oscillating the magneto in the slots and, if this condition is not obtained, remove the magneto once more. Remove the magneto drive coupling retaining nut cotter pin, place the holding tool over the coupling splines, remove the nut using a box socket wrench. The magneto drive coupling is splined to the magneto shaft. Remove the coupling, turn to the next spline, and reinstall on the shaft. Install the washer and nut and replace the magneto on the engine. Check the opening and closing of the points and, if satisfactory, remove the magneto, tighten the nut, and lock it with a new cotter pin. All adjustments must be made at the drive end of the magneto and not by altering the breaker point adjustment.

Move the magneto in the direction opposite to crankshaft rotation until the breaker points open and insert a 0.001-in. feeler between them. Move the magneto as far as it will go in the direction of crankshaft rotation so that the breaker points have closed on the feeler stock. Tap the magneto slowly back in the other direction until the feeler gage begins to move, indicating that the breaker points are just beginning to open. Tighten the flange attaching nuts to secure the magneto in this position.

Turn the crankshaft in the direction of rotation until the timing disk pointer indicates the timing position for the remaining magneto as indicated on the engine data plate.

Install the remaining magneto following the procedure previously mentioned for the installation of the first magneto.

Check the timing of both magnetos by installing a 0.001-in. feeler gage between the points of each magneto. Turn the crankshaft in the opposite direction of normal rotation approximately one-quarter turn. Move the crankshaft slowly in the direction of rotation by tapping the turning hub handle until the magneto points just begin to open at the position of spark advance in accordance with the figures noted on the engine data plate (see Fig. 45).

If the opening of the magneto points does not coincide with the figures noted on the engine data plate, loosen the magneto attaching nuts, turn the crankshaft to the proper timing setting as indicated on the timing disk. readjust the magnetos, and recheck the timing.

When the correct timing has been established, check the attaching nuts for tightness and secure them with cotter pins.

It may be found that the timing marks *A* on the distributor rotor are not exactly in line with the marks on the front end plate after the magnetos are

properly adjusted and timed. However, a misalignment of 1/32 in. of these two marks will not affect the operation of the magnetos.

The magnetos may also be timed and checked using a light attached to batteries. If this method is used, follow the same procedure previously described except that it will be necessary to insert an insulator in the primary circuit to prevent battery current from flowing through the coil. The coil is insulated from the breaker points by removing the breaker point to coil connector attaching screw located at the breaker point support. Make sure that the connector is not making contact, connect the checking light wires across the breaker points, and check the magneto timing.

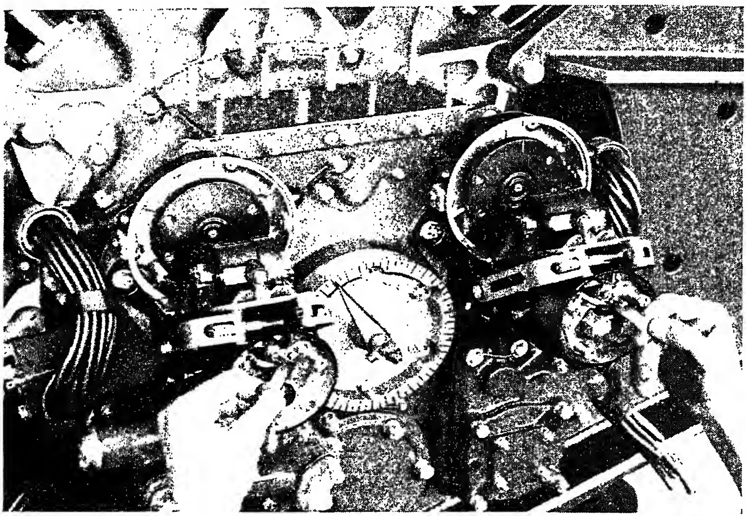


FIG. 45.—Checking magnetos after installation.

After the magneto has been properly timed, remove the checking light wires and reconnect the breaker point to coil connector by installing and tightening the attaching screw.

Some engines are equipped with magnetos designated as SF14-4 or compensated magneto. This type magneto differs from other types in that it is equipped with a 14-lobe breaker cam and may be identified in this manner as well as by the data plate attached to the magneto. The compensated type magneto is timed to the engine in the manner described for other types of magnetos except that the marked lobe on the breaker cam must be in the position to open the breaker points when the *A* and *B* marks on the distributor finger and magneto housing and the step in the cam and the marks *M* simultaneously index.

If the magneto has been correctly assembled at the time of overhaul or original assembly, the No. 1 or marked cam lobe will be in the correct position in relation to the other marks, but it is recommended that before

the magneto is assembled to the engine these marks be checked and, if the cam lobe 1 is not in the correct position for opening the points when other marks are indexing, do not install the magneto on the engine until it has been rechecked and the proper repairs made.

The magnetos may also be installed and checked for proper timing by using the timing scale on the reduction drive gear instead of a timing disk (Fig. 46).

Checking Valve Timing.—Check the valve timing by installing a top center indicator in the front spark-plug hole of cylinder 1 (top cylinder of rear row). Mount the timing disk to suit the engine. First proceed as in timing the magneto, as described on page 151, then adjust the clearance of both valves to the timing value specified on the engine data plate.

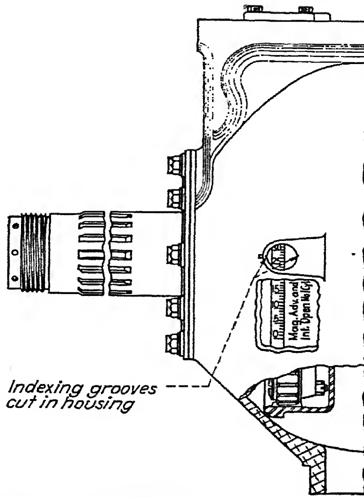


FIG. 46.—Timing scale on reduction driving gear.

Turn the crankshaft in the direction of rotation approximately 150 deg. or until the piston in cylinder 1 is 30 to 35 deg. before top center on the exhaust stroke. From this point move the crankshaft forward slowly by tapping the turning hub handle until the intake rocker roller 1 just contacts the valve stem tip, indicating that the valve is starting to open. As soon as the roller tightens against the valve tip, note the reading on the timing disk. Continue to turn the shaft forward until exhaust rocker arm roller 1 is free, indicating that the exhaust valve has closed and note the reading on the timing disk. If the cam gears have been meshed properly, the valve clearance adjusted accurately, and the check carefully made, the readings obtained should check within a few degrees of the valve timing specifications given on the engine data plate. An error of one tooth made in the meshing of the cam gears will cause the readings obtained to vary considerably from the specified timing.

The timing scale on the reduction driving gear may also be utilized when checking the timing of the rear cam.

Continue to turn the crankshaft in the direction of rotation until the piston in the next cylinder in firing order sequence is at the top of its stroke. Adjust the timing disk pointer to read zero when the piston in this cylinder (No. 10, front row) is in its top center position in the manner previously described for adjusting the time disk for the top center position of the piston in cylinder 1. Check the valve timing of the front row cylinder in the same manner described for the rear row cylinder 1. The timing scale on the reduction driving gear cannot be used for reference when checking the timing of the front cam.

After completing the valve timing check, reset the valves in both cylinders following the instructions given regarding the location of the oil holes in

the adjusting screws. Pour one-half pint of engine lubricating oil into the rocker boxes and install the rocker box gaskets and covers.

Remove the timing disk from the starter mounting pad and reinstall the gasket and cover plate.

Remove the top center indicator and reinstall the dummy spark plug. Install the plug in the front section inspection hole and secure with stainless-steel safety wire.

Spark Plugs.—Spark plugs that have been sprayed with preservative compound should be thoroughly cleaned, dried out, and bomb tested before they are installed in an engine. Plugs should be cleaned with a gasoline spray, blown dry with air, and placed in a moderately heated oven for a sufficient length of time to ensure removal of all moisture.

The gaps should then be checked and if found greater than 0.012 in., they should be adjusted to this figure. Bomb test each spark plug at 150-lb. pressure, using carbon dioxide. Check the tightness of the solid type copper spark-plug washer and the spark-plug washer type thermocouples. Do not use either type if it does not conform to the following limits: minimum thickness 0.068 in., maximum thickness 0.095 in.

Remove the dummy spark plugs. Install solid copper washers on all the spark plugs except those that use the thermocouple type washer. Install and tighten the spark plugs to the proper torque value using the proper wrench for plugs having a ⅞-in. hex nut and a wrench for plugs with a 1-in. hex nut. (Refer to Table 5.)

Use extreme care when tightening spark plugs if the engine is hot. Excessive tightening under this condition may cause the plugs to seize in the insert when the engine cools, which may result in damage to the insert or cylinder insert hole when removal of the plug is attempted.

Before attaching the spark-plug elbows to the spark plugs, clean the contact sleeves with a cloth saturated with carbon tetrachloride and do not touch them with the fingers since the salt from any perspiration which might be on the hands will produce arcing and corrosion.

EMERGENCY TREATMENT OF ENGINE AFTER SUBMERSION IN SALT OR FRESH WATER

The problem of preventing corrosion or rusting of engine parts is comparatively simple when it is necessary to deal only with the effect of atmospheric moisture on steel. If however an engine, through mishap, has been submerged in either salt or fresh water, the problem of arresting corrosion becomes exceedingly difficult and precautions correspondingly more necessary.

Engines can be guarded against atmospheric moisture by slushing. In the case of an engine that has been submerged the problem then is to stop corrosive action that has already started and prevent any further corrosion. In order that the reasons for the method employed may be better understood the following brief discussion of corrosion is offered.

Corrosion was first believed to be a case of simple oxidation; it is now generally understood that water must be present as well as oxygen. Experiments were made in which polished samples of iron were submerged in distilled water that had been boiled to expel all the air and carbon dioxide. The samples were submerged and the containers sealed while the water was still boiling. No rust formed nor was there any sign of corrosion after the samples had been in the water for several weeks. Following this the

containers were opened and air admitted, with the result that corrosion immediately started. From this it can be concluded for practical purposes, that steps must be taken to prevent oxygen from reaching iron or steel parts that have been in contact with water if corrosion is to be retarded. In addition, the water must be removed as quickly as possible since oxygen is present in the water.

There are many factors that influence the rate of corrosion such as the condition of the atmosphere, the temperature, and the material involved. The more humid the atmosphere the higher the rate of corrosion. Also, corrosion is accelerated by higher temperatures, although this may be linked to the former owing to the fact that air at higher temperatures can carry a greater amount of moisture. The nature of the material also has a great influence on the rate of corrosion.

First the water must be removed from all parts and secondly, if this is not possible, the parts must be so treated to prevent contact with the atmosphere. In the case of a complete engine it is extremely difficult to accomplish this first provision, owing to the inaccessibility of the parts. A complete teardown of the engine is required and unfortunately proper equipment for this operation is rarely available at the scene of submersion. This brings in the element of time; therefore means must be taken to prevent corrosion, as far as possible, until the time when the engine is completely dismantled and each part cleaned. The action of the air creates corrosion; therefore all parts of the engine should be coated as thoroughly as possible with oil to prevent the air from reaching them. It is so important that the air be kept from contacting the wet steel parts that in a case where oil is not available it is often better to allow the engine to remain under water until some slushing medium is obtained providing, of course, that this can be done within a reasonable length of time.

Too much stress cannot be laid on the importance of working quickly if it is expected that the engine is to be salvaged; therefore, arrangements must be promptly made to dismantle the engine as quickly as possible and thoroughly clean and slush each part. If the submersion occurred in salt water, it is recommended that, as soon as the engine is dismantled, all parts other than electrical equipment be washed in hot, fresh water, dried, and slushed with lubricating oil that has been heated to 180°F. Electrical equipment such as starters and generators should be thoroughly flushed with fresh water, dried, and overhauled before using. When accessories are being overhauled, they should be visually checked for detrimental corrosion, the condition of all insulation determined, and all electrical circuits thoroughly tested before reassembly. All windings that are otherwise serviceable should be baked in an oven at 140°F., for 4 hr. before reassembly. Ignition wire manifold rings may be salvaged, but all flexible conduit and ignition wire must be replaced. Replace magnetos that have been submerged in either fresh or salt water, with new or reconditioned instruments.

A careful inspection must be made of each part salvaged to ascertain not only the extent of damage caused by corrosion but also for other defects caused by the sudden cooling action of the water in cases where the engine was at operating temperature at the instant prior to submersion. In cases where the engine has been submerged in salt water for any length of time, it is reasonable to expect that parts of aluminum and particularly those made of magnesium will have been destroyed.

SECTION V

LYCOMING OPPOSED-CYLINDER ENGINES

The Lycoming, opposed-cylinder engines are in the low-power, air-cooled engine class. The O-145 is rated at from 50 to 75 hp. depending on compression and r.p.m. The GO-145 engine has the same bore and stroke, is rated at 75 hp., but differs in being geared down with a 27 to 17 ratio. This gives an engine speed of 3,200 r.p.m. and a propeller speed of 2,015, permitting the use of a larger propeller.

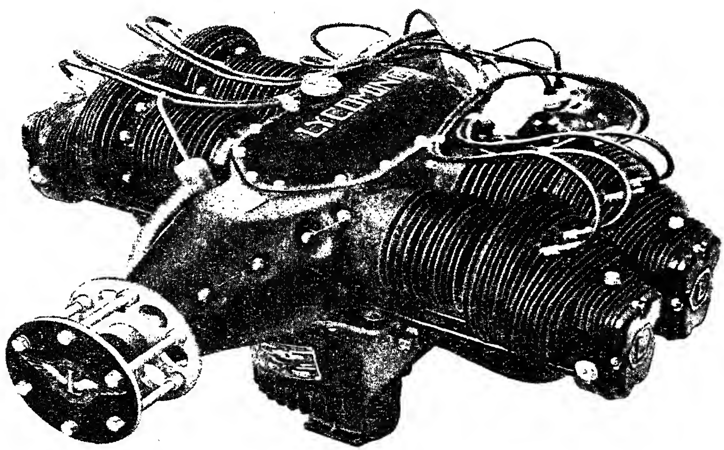


Fig. 1.—Lycoming GO-145-C2 75-hp. geared engine.

Both types are described and the differences noted; both are shown in Figs. 1 and 2. Figure 3 shows a section of the O-145 engines and Fig. 4 the GO-145-C3 engine with the reduction gear case and other accessories. Figures 5 and 6 give the dimensions necessary in planning the installation of O-145 engines. The GO-145 is about 6 in. longer from the cylinders to the propeller hub on account of the reduction gears. Figure 7 shows the lubrication system.

The 17-tooth pinion of the crankshaft of GO-145 is held by a nut and lock washer.

LYCOMING MODEL O-145

The Lycoming model O-145 aircraft engine is a four-cylinder direct drive, horizontally opposed and air cooled. The A, B, and C series are identical in design with only such changes in construction as to permit the different horsepower ratings.

The A series is rated at 50 to 55 hp. at 2,300 r.p.m.; B Series at 65 hp. at 2,550 r.p.m.; and C Series at 75 hp. at 3,100 r.p.m. The numeral following the letter denotes the equipment on the engine, that is, "1" single ignition, "2" dual ignition, "3" dual ignition with generator and starter drive. All engines can be furnished with fuel pump drive if desired.

Some of the parts for the B and C Series that differ from the A Series are camshaft, exhaust valves, valve springs, pistons, accessory gears, and connecting rod bearings. The crankshaft is of forged molybdenum steel, nitrided to produce a hard surface on journals and crankpins. Under no circumstances should any attempt be made to straighten this shaft.

The magneto timing on the various types is as follows:

O-145-A1, C1	28 deg. B.T.C.
O-145-B1	22 deg. B.T.C.
O-145-A2, A3, B2, B3	20 deg. B.T.C.
O-145-C2, C3	25 deg. B.T.C.

The method of timing the engines is explained on page 178.

Unless otherwise specified, these instructions apply to the B and C Series, as well as to the A series.

Oil Recommendations

	Series	
	O-145-A	O-145-B and C
Summer, temperature above 40°F	S.A.E. 30	S.A.E. 40
Winter, temperature below 40°F	S.A.E. 20 W	S.A.E. 30

Operation. *Lubrication System.*—The lubrication system is of the full-pressure type, with wet sump, except for the engine oil which is led to the valve rocker bearings. Cylinder walls and pistons are lubricated by excess oil thrown from the crankpins. Oil pressure oil pump is mounted in the accessory housing.

Oil is drawn directly from the sump by the pump and is forced past the oil pressure relief valve to the drilled hole in the camshaft to the cam bearings. From the cam bearings it is forced to the crankshaft bearings and through the crankshaft from the crankshaft journals to the crankpins. Excess oil from the crankpins lubricates the cylinder walls, pistons, and gears, then drains back through the oil screen to the sump. A constant flow of oil is supplied from the crankcase to the rocker arms and valve mechanism through the tappet assemblies and push rod housings.

Oil pressure is controlled by the oil pressure relief valve mounted in the accessory housing, and the desired pressure is obtained by increasing or decreasing the number of washers over the oil relief valve spring.

Starting.—Before starting the engine, check for the proper oil level in the engine sump by means of the oil level gage in the breather pipe in

Table 1.—General Lycoming Model O-145 Engines
(The following table gives an outline of the main features of the different engines built in this class)

	Series								
	O-145-A1	O-145-A2	O-145-A3	O-145-B1	O-145-B2	O-145-B3	O-145-C1	O-145-C2	O-145-C3
Engine type certificate	199	199	199	210	210	210	210	210	210
Rated horsepower	50	55	55	65	65	65	75	75	75
Rated r.p.m.	2,300	2,300	2,300	2,550	2,550	2,550	3,100	3,100	3,100
Cruising r.p.m.	2,100	2,100	2,100	2,300	2,300	2,300	2,800	2,800	2,300
Bore	3⅝	3⅝	3⅝	3⅝	3⅝	3⅝	3⅝	3⅝	3⅝
Stroke	3½	3½	3½	3½	3½	3½	3½	3½	3½
Compression ratio	5.65 to 1	5.65 to 1	5.65 to 1	6.5 to 1	6.5 to 1	6.5 to 1	6.5 to 1	6.5 to 1	6.5 to 1
Piston displacement, cu. in.	144.5	144.5	144.5	144.5	144.5	144.5	144.5	144.5	144.5
Head temperature, max. °F.	525	525	525	525	525	525	525	525	525
Barrel temperature, max. °F	325	325	325	325	325	325	325	325	325
Oil temperature, max. °F	220	220	220	220	220	220	220	220	220
Fuel octane	73	73	73	73	73	73	73	73	73
Fuel consumption, cruising bhp. per hr. max., lb	0.55	0.55	0.55	0.50	0.50	0.50	0.50	0.50	0.50
Oil sump capacity, qt	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5
Oil sump, safe quantity, qt	2½	2½	2½	2½	2½	2½	2½	2½	2½
Oil pressure:									
Min. idling, lb	15	15	15	15	15	15	15	15	15
Normal operating, lb	55–80	55–80	55–80	55–80	55–80	55–80	55–80	55–80	55–80
Crankshaft rotation, antipropeller end	Clockwise	Clockwise	Clockwise	Clockwise	Clockwise	Clockwise	Clockwise	Clockwise	Clockwise
Valve clearance—intake and exhaust—cold, in	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Spark occurs, deg. B.T.C	28	20	20	22	20	20	28	25	25
Firing order	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4	1–3–2–4
Spark plugs:									
Edison-Splitdorf 0.025-in. gap	HC-83	HC-83	HC-83	HC-83	HC-83	HC-83	HC-83	HC-83	HC-83
Champion available 0.025-in. gap	LM-3-1	LM-3-1	LM-3-1	LM-3-1	LM-3-1	LM-3-1	LM-3-1	LM-3-1	LM-3-1
Engine dry weight including carburetor, magneto or magnetos, and spark plugs, lb	152	162	164	155	165.5	167.5	155	165.5	167.5
Propeller hub and baffles, lb	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
Engine total weight, lb	157.33	167.33	169.33	160.33	170.83	172.83	160.33	170.83	172.83
Radio shielding—added weight, lb	0.54	1.18	1.18	0.54	1.18	1.18	0.54	1.18	1.18
Carburetor:									
Marvel*	MA-2	MA-2	MA-2	MA-2	MA-2	MA-2	MA-2	MA-2	MA-2
Altitude control available	Available	Available	Available	Available	Available	Available	Available	Available	Available
Magneto—Scintilla SF-4L	One	Two	Two	One	Two	Two	One	Two	Two
Fuel pump	Available	Available	Available	Available	Available	Available	Available	Available	Available
Generator and starter	None	None	Available	None	None	Available	None	None	Available

* Model of carburetor same for all engines but jet size different.

front of the engine. Turn the fuel valve to the "on" position and prime the cylinders with one or two shots of the priming pump. Be sure the ignition switch is in the "off" position and, with the throttle closed, rotate the propeller in the direction of rotation four or five revolutions. Open the throttle slightly, turn the ignition switch to the "on" position and pull the propeller through. If the engine fails to start, repeat the operation without additional priming. If the cylinders should become loaded with an excessive amount of raw gasoline, open the throttle wide and rotate the propeller backward five or six revolutions before attempting to start again.

After the engine starts and is firing evenly, open the throttle until the engine is turning 900 to 1,000 r.p.m. to warm up. Oil pressure should be indicated within ½ min. after the engine is started. The engine is warm

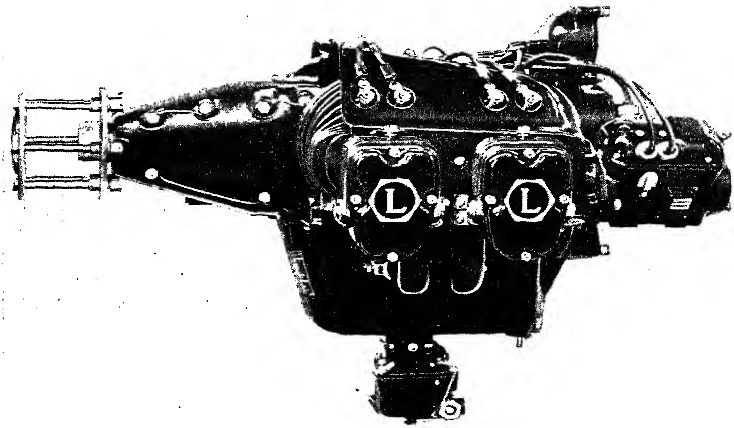


FIG. 2.—Side view of GO-145 Lycoming 75-hp. geared engine.

enough for the take-off when the throttle can be opened wide and no missing or backfiring occurs.

On dual ignition engines, a maximum of 25 r.p.m. is allowed in drop-off when switching from one magneto to the other.

To adjust the idling speed of the engine, follow the instructions as given under Adjustment, Marvel carburetor, in a later section.

Carburetor Heater Control.—When the outside air temperature is below 50°F. or at such times when there is evidence of carburetor icing, the carburetor heater control should be operated to prevent the formation of ice in the carburetor venturi and to improve the vaporization and distribution of fuel to the cylinders. In warm weather, except at high altitudes, the control should be left in the full cold position to permit the engine to develop maximum power.

Carburetor Mixture Control.—The carburetor mixture control should be used to maintain the proper ratio of air and fuel when operating the engine at altitudes above 5,000 ft. Under no circumstances, especially at full

throttle, should any position other than full-rich mixture be used for all flying under 5,000 ft. above sea level.

When flying at altitudes above 5,000 ft. at any throttle setting, adjust the carburetor mixture control toward the "lean" position until the maximum engine r.p.m. is obtained. Too lean a mixture will result in overheating with subsequent damage to the engine. Care should be taken to readjust the control for each change in the throttle setting and, particularly, to return the mixture control to the "full-rich" position prior to an approach for landing or a descent to a lower altitude.

Operation in Flight.—The propeller used must allow the engine to turn its rated r.p.m. at full throttle in a climb at sea level. The oil pressure recommended for cruising is shown in the specifications. When the engine is operated on dusty or sandy airports, it is recommended that an air cleaner be installed.

Stopping Engine.—After landing, allow the engine to idle for a short period before turning off the ignition. If the engine should "after-fire" when the switch is turned off, the switch should be turned on immediately and the engine allowed to idle for another short period before the ignition is again turned off.

Servicing.—Lubricating oil used in Lycoming model O-145 engines should be changed after every 30 hr. of flying. All drained oil should be inspected for general condition and for any accumulation of foreign material. At each oil change period the carburetor should be serviced in accordance with instructions on Marvel MA-2 aircraft carburetors.

Daily Inspection.—Before the first flight each day, a visual inspection should be made as outlined below to determine the general condition of the engine and to ensure proper functioning of the fuel system, engine controls, instruments, etc.

1. Inspect the fuel line strainer. If any dirt or water has collected in the bottom of the strainer, drain the strainer and fuel lines and resafety.
2. Inspect the oil and fuel lines and connections for leaks.
3. Check the ignition cables for proper connections.
4. See that the safety wire on the propeller hub bolts is properly secured.
5. Check the engine controls for full range of free operation.
6. Check the quantities of fuel and oil and see that the filler caps are properly secured.

After the first 10 hr. on a new or an overhauled engine a thorough inspection should be made of the engine and the installation.

1. All exterior nuts, bolts, and screws should be checked for tightness. Since the engine is cushioned against vibration by means of rubber washers between the engine and the mount, care must be taken to prevent tightening the engine mounting bolts too tightly, which will damage the washers and force them out of position.
2. Check the propeller hub attaching bolts for tightness. The bolts must be tightened evenly in order that the propeller hub be properly located on rear flange pilot bosses. Check the propeller blades for track by means of a point located from a fixed position on the airplane. If the blades are out of the track more than $\frac{3}{32}$ in., the hub bolts have been tightened more on one side than on the other. Loosen the bolts and retighten evenly, again checking for track.
3. Drain the oil by removing the drain plug in the bottom of the oil sump. Each subsequent oil change should be made at 25 to 30 hr. of flying time.

4. Remove the rocker box covers and adjust the valves to 0.015 in. clearance. When reinstalling the rocker box covers care must be exercised to prevent warpage of the covers by excessive tightening of the hold-down nuts.
5. Inspect all oil and fuel lines for leaks, and the connections for security.
6. See that the throttle control travels full range without binding.
7. Remove the magneto breaker cover by the two knurled head securing screws and remove any excess oil from the inside of the cover and around

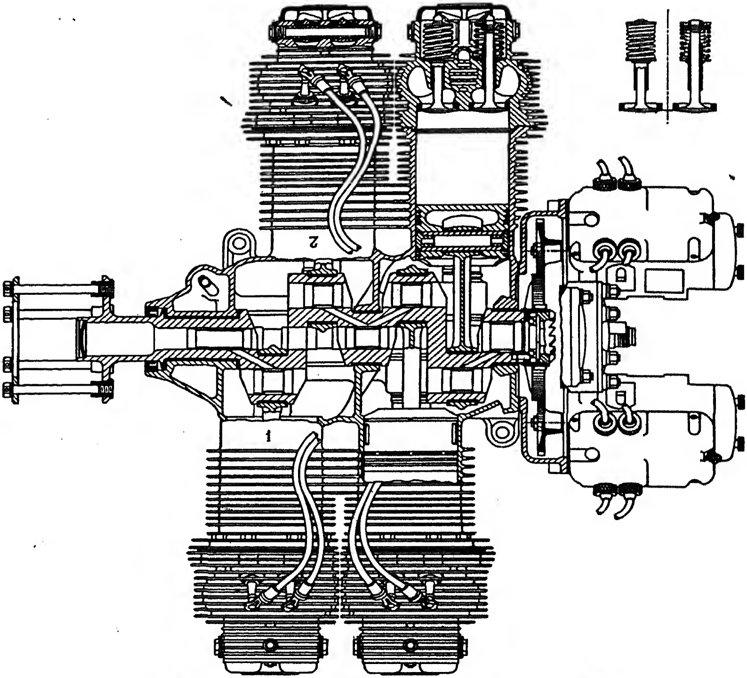


FIG. 3.—Section of Lycoming opposed engine—direct drive.

the breaker mechanism. Thoroughly clean and dry the breaker mechanism to ensure that oil will never touch the breaker contacts.
8. Fill the oil sump through the filler cap on top of the engine with 4 or 5 qt. of oil of the proper grade.
9. Start the engine and check the idling adjustment in accordance with instructions.

100-*hr. Inspection.*—This should be a complete engine check and include the items already outlined, in addition to the following:
1. Remove the spark plugs, clean and adjust the electrodes to a gap of 0.025 in., then test them for proper firing in a bomb under 90-lb. pressure.

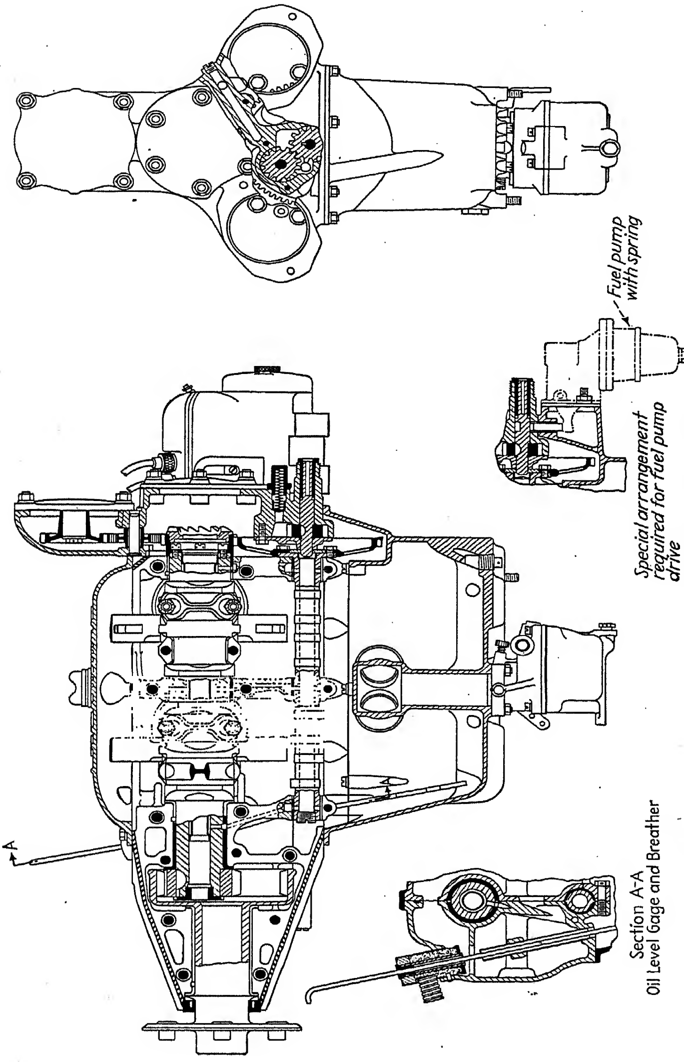


FIG. 4.—Section of Lycoming geared engine.

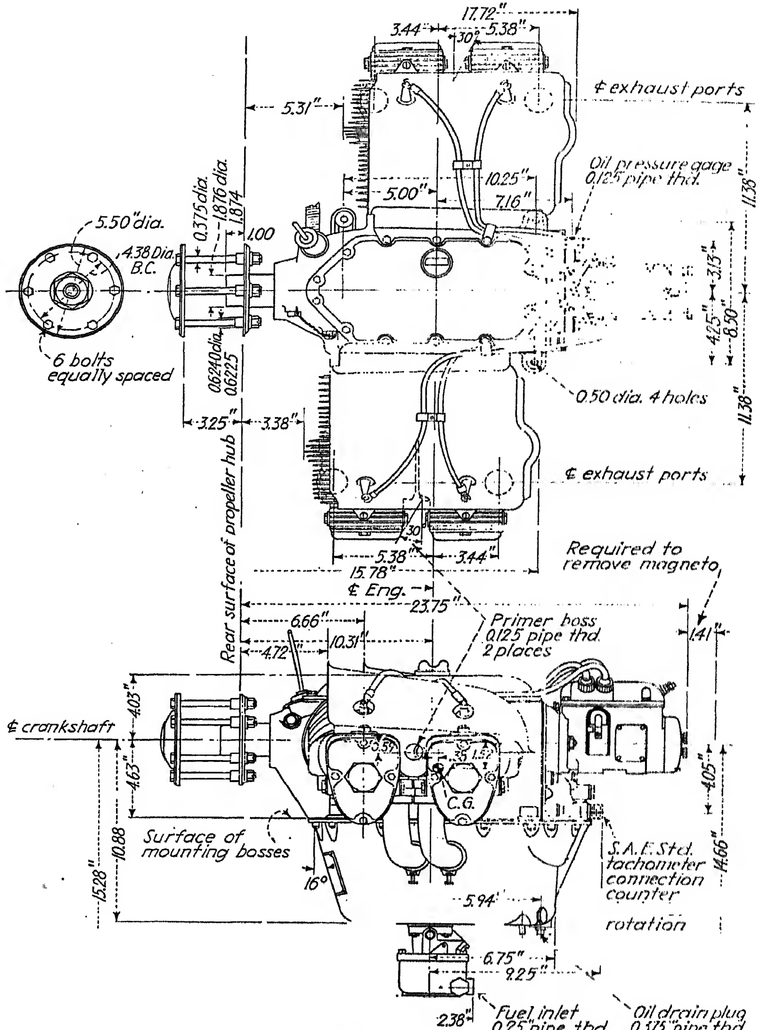


FIG. 5.—Installation drawings of Lycoming O-145-type engine.

2. *Valves are to be adjusted after the cylinder head hold-down nuts have been checked.*

3. Check the magneto breaker points for general condition. If found to be pitted, the points should be carefully dressed to obtain as nearly perfect contact as possible. Check the magneto or magnetos for correct timing according to the detailed instructions given on pages 178 and 179. This is a very important part of engine overhaul.

4. Remove the gas strainer plug and strainer from the carburetor and clean the strainer.

5. Check the starter and generator in accordance with the manufacturer's instructions.

6. Check the intake pipe hose connections for proper tightness.

7. Carefully check the engine mount for cracks and check the engine mounting washers and rubbers for condition and proper tightness.

After the first 100-*hr. on a new engine*, it is recommended that the throttle control and fuel inlet connection at the carburetor be disconnected and the oil sump be removed from the crankcase. Thoroughly clean all foreign materials from the oil strainer. Reinstall the oil sump using a new oil sump gasket on which a coating of nonhardening gasket sealing compound has been applied. Using ¼-in. plain washers, shakeproof lock washers, and screws, tighten the oil sump in place. Connect the throttle control and fuel inlet connection to the carburetor. See that full and positive movement of the throttle control is permitted.

Disassembly.—A portion of the disassembly is performed with the engine installed in the plane, the work being completed on a bench, an engine stand not being necessary. As each separate part is removed, it should be given a careful visual inspection before cleaning in order to detect any unusual conditions, such as a collection of metal particles or heavy sludge. Shaft, gears, and bearings should be inspected for free movement and, as far as possible, a complete check made of the entire engine for worn or damaged parts.

As the crankcase consists of two halves, references will be made to the right and left crankcase. The right crankcase carries cylinders 2 and 4; the left crankcase, cylinders 1 and 3. Cylinder numbers are cast on the crankcase at the base of the cylinder barrels and stamped on the side of each cylinder head.

Remove the six ⅜-in. nuts and bolts in the propeller hub and remove the propeller with the front flange.

Disconnect the throttle control and fuel inlet connection at the carburetor. If a fuel pump is used, disconnect the fuel connection to the fuel pump and to the carburetor. Remove four ¼-in. nuts attaching the carburetor to the oil sump and remove the carburetor.

Remove the oil drain plug in the bottom of the sump and drain the oil.

Disconnect the tachometer connection and oil pressure line at the engine. Remove the oil temperature bulb and primer lines.

Disconnect the ignition cable terminals from the spark plugs and remove the spark plugs.

If the engine is equipped with an external rocker box venting system, disconnect the rocker box vent tubes at the rocker boxes and at the crankcase cover, and remove the vent tubes.

Remove the screw from the boss on top of each cylinder head and the ¼-in. crankcase cover screws that secure the cylinder baffles and remove the baffles.

Loosen the exhaust pipe clamps at the cylinder outlets and remove the exhaust stacks.

If a starter and generator are used, remove the connections.

Remove the ground wire from the magnetos.

Remove the intake pipes as follows: Loosen both hose clamps on the connection at the crankcase end of the intake pipe and slide the hose connection

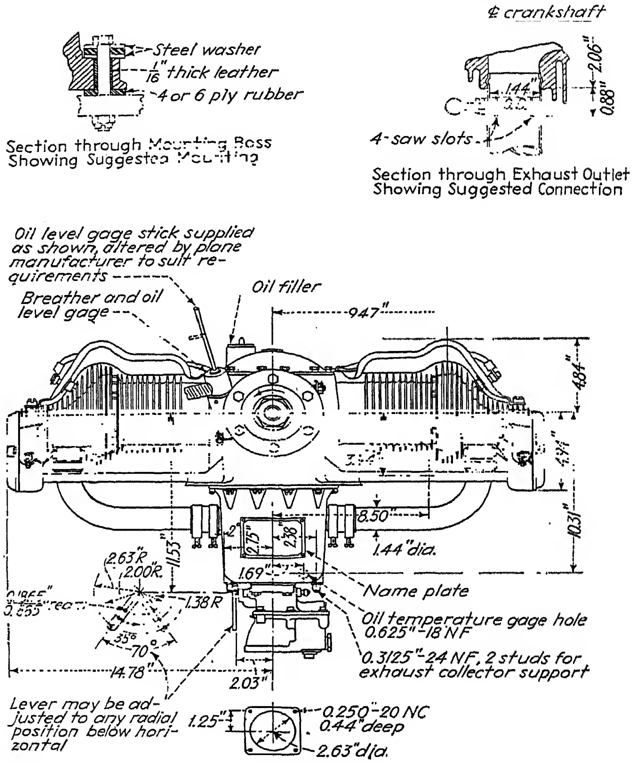


FIG. 6.—End view of engine in installation drawings.

back on the intake pipe. Loosen the hose clamp on the connection at the other end of the intake pipe allowing the clamp that secures the connection to the cylinder head to remain tight. The intake pipe may now be easily removed. Remove the hose connection from the cylinder head. The intake pipes for the rear cylinders should first be removed and the intake pipes for the front cylinders should be first installed.

Remove the mounting nuts and bolts that secure the engine to the engine mount. Remove the engine from the airplane by means of a sling passed under the cylinder barrels on each side of the crankcase. *Be sure the sling passes between the push rod shroud tubes and cylinder barrels close to the crankcase.* Place the engine on a bench, resting on blocks on the bottom of the sump.

Remove the $\frac{5}{16}$-in. nuts attaching the magneto to the accessory housing and, on A1 Series engines, remove the magneto with the magneto coupling assembly. On A2 and A3 engines, remove the magnetos with the magneto drive gears. Remove the magneto gasket. On A1 engines, remove the magneto coupling assembly from the magneto; on A2 and A3 engines, remove the magneto gear using a suitable puller. The coupling assembly or gears need not be removed unless repair or replacement is to be made.

Unscrew the knurled nut that secures the ignition cables to the magneto and remove the cables.

On A3 engines, remove the $\frac{5}{16}$-in. nuts attaching the starter and generator to the accessory housing and remove the starter and generator. Remove the cap screw that attaches the generator drive gear to the generator and remove the screw with the washer and remove the gear.

On A3 and A2 engines, if a fuel pump is used, remove the $\frac{5}{16}$-in. nuts attaching the fuel pump and remove it.

Remove the oil relief adjusting screw with washers, spring, and plunger from the accessory housing.

Remove the balance of the screws from the crankcase cover and remove the cover and gasket. Remove the nuts from the rocker box cover studs and remove the covers and gaskets.

Remove the $\frac{5}{16}$-in. nuts attaching the cylinder heads to the cylinder barrels and remove the cylinder heads with the shroud tubes and push rods. When the heads are being removed, the push rods and shroud tubes must be held with one hand to prevent their falling out. Remember the cylinder head gaskets.

Turn the engine on the right side so that the flanged surfaces of cylinders 2 and 4 are resting on the bench. Remove the twelve $\frac{1}{4}$-in. screws that attach the oil sump to the crankcase and remove the four $\frac{1}{4}$-in. nuts from the studs in the bottom of the accessory housing. Remove the oil sump with gasket. Also remove the six $\frac{1}{4}$-in. screws that attach the oil strainer to the inside of the oil sump and remove the oil strainer. If a fuel pump is used, remove the fuel pump plunger with the circlip from the oil sump.

Remove the $\frac{5}{16}$-in. screws that attach the accessory housing to the crankcase and remove the accessory housing and gasket.

Remove from the accessory housing the $\frac{1}{4}$-in. screws that attach the oil pump cover and remove the lock plate and cover. The oil pump and tachometer drive shaft, the oil pump drive gear and key, and the oil pump idler shaft and gear may now be removed. Remove the tachometer shaft seal from the tachometer shaft housing boss. On A2 and A3 engines remove the tachometer shaft seal washer located behind the seal.

On A3 engines, if the generator is used, remove the generator idler gear pin from the accessory housing by inserting a 10-32 puller screw in the tapped hole in the end of the pin and by drawing the pin from the housing. Remove the seal from the pin. Remove the generator idler gear.

On A3 engines, remove the starter jaw from the crankshaft gear by holding a wooden block against the rotation of the crankshaft and by inserting a $1\frac{1}{4}$-in. hex drive wrench inside the starter jaw. Strike the handle of

the wrench a sharp blow with a hammer to loosen. Right-hand threads are used on the starter jaw.

Remove the four 1/4-in. screws from the crankshaft gear and remove the gear.

Remove the four 1/4-in. screws attaching the camshaft gear to the end of the camshaft and remove the lock plate and gear.

Remove the 3/8-in. slotted nuts and the connecting rod caps from the connecting rods of cylinders 1 and 3. Carefully push the connecting rods and pistons out through the top of cylinder barrels 1 and 3 being careful not to damage any parts. The two crankcase sections should now be separated

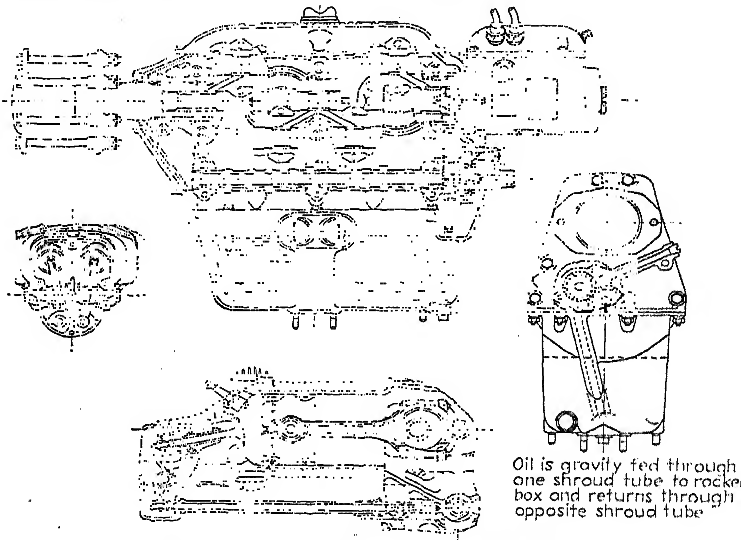


FIG. 7.—Lubrication system of Lycoming engines.

in order to make more accessible the removal of the connecting rods and pistons in cylinders 2 and 4.

To separate the crankcase sections, remove the three 3/8-in. cap screws and one 3/8-in. nut that hold the crankcase section together in front of cylinders 1 and 2. Remove the two 3/8-in. nuts attached to the studs between cylinders 1 and 3. Remove the two 3/8-in. nuts from the studs on the inside of the crankcase at the rear of the engine, and three 5/16-in. cap screws on the camshaft bearing bosses on the bottom of the crankcase. By tapping against a fiber drift or wooden block held inside the crankcase against the heavy portion of the left crankcase section, one-half of crankcase may be removed. *When the crankcase is being separated, particular care must be used to prevent damaging the crankshaft or the camshaft.*

The connecting rods and pistons in cylinder bores 2 and 4 may now be removed.

Carefully lift the crankshaft and camshaft from the right crankcase section. Remove the crankshaft oil seal from around the crankshaft.

See that the crankshaft and camshaft bearings are kept in their original location in the crankcase. If a bearing should drop out of the crankcase during disassembly, be sure it is replaced in its proper location. Bearings are not to be removed unless inspection indicates that replacement is necessary.

Remove the valve tappet assemblies from inside the crankcase.

Remove the two crankcase oil seals and four oil seal rings from the right crankcase.

Remove the piston-pin plugs from the piston pins and push or tap out the piston pins from the pistons and connecting rods.

Remove the piston rings from the pistons being careful not to scratch or damage the pistons.

Remove the valve rocker shaft plugs and gaskets from the cylinder heads and tap out the valve rocker shaft using the suitable drift. The valve rockers and valve rocker shaft washers may now be lifted out. Remove the $\frac{5}{16}$-in. nuts from the valve adjusting screws and remove the valve adjusting screws from the valve rockers.

Place the cylinder head on a suitable block that will support the valves against the seats. Insert the drift through the valve rocker shaft bosses and, using a valve spring compressor, compress the valves and remove the valve keys. Also remove the valve springs, the valve spring upper and lower seats, and the valve stem circlips. Remove the valves from the cylinder head.

Cleaning.—Following the disassembly of the engine and prior to inspection, all parts are to be thoroughly cleaned. Engine parts should be cleaned with compressed air and a flushing fluid such as gasoline, Varnoline, or Varsol. Do not use chemicals or strong cleaning solutions, particularly on the crankcases. The inside of the crankcases is treated with a special solution and painted to seal the metal. *This paint must not be removed.* If any portion of the paint should be scratched, damaged, or otherwise removed, the surface should be repainted with crankcase sealer, such as duPont's Orange Engenamel. After cleaning, all parts should be thoroughly rinsed and dried and, if steel parts are to remain on the rack for any length of time after cleaning, the entire surface of each part should be coated with clean engine oil. Hard carbon deposits on the pistons and cylinder heads may be removed by very careful scraping, using every precaution to avoid removing any metal.

All oil passages in the crankcase, accessory housing, camshaft, and crankshaft should be thoroughly cleaned with compressed air and flushing fluid. A crankshaft oil tube is pressed in the oil passage at each crankshaft journal and a crankpin oil tube is pressed in the oil passage at each crankpin. Sludge that is formed in the oil during engine operation collects at these oil tubes and it is necessary to use extra precaution when cleaning the crankshaft to see that all oil passages are clean. *The crankshaft and crankpin oil tubes must be removed,* to facilitate cleaning of the oil passages. The oil tubes can be driven out with a steel drift, passing the drift through the inner bore of each crankshaft journal or crankpin. If oil tubes have been removed and not replaced, new tubes must be installed.

Inspection.—The following general instructions apply in addition to the specific items outlined in the inspection procedure for various parts:

1. Inspection of all parts for cracks should be performed with the aid of a magnifying glass.

2. All finished surfaces, such as mounting flanges and bearing surfaces, should be carefully examined for scores, nicks, burrs, corrosion, and roughness. Flanged surfaces should also be checked for evenness against a true flat surface.

3. Gears should be carefully inspected for wear, cracks, nicks, burrs, or severe pitting on gear teeth. Also inspect the gears for evidence of improper meshing of the teeth.

4. Bearings and bushings should be checked for wear, scoring, and tightness in mounting.

5. Following the repair of bearing surfaces, a check of the clearances between operating parts should be made with micrometer instruments or thickness gages. The measured clearance should be checked against the list Service Fits and Clearances on page 184. Parts worn beyond the maximum permissible clearance should be replaced.

6. Studs should be checked for straightness, condition of threads, and tightness.

7. All washers, nuts, lock nuts, and screws should be inspected for cracks, nicks, burrs, and for condition of threads. Lock washers should be replaced. Slightly damaged washers, nuts, and screws may be dressed satisfactorily. Any case of stretched or damaged threads requires replacement of the part.

8. Hose clamps that are stretched, bent, or otherwise damaged are to be discarded.

9. Overhaul of accessories should be done only by service stations authorized by the manufacturer of the accessory.

Bearings.—Crankshaft and camshaft bearings and journals must be checked for wear with the crankshaft and camshaft installed and the left and right crankcases assembled. See that all bearings are in their proper locations. Place a 0.006-in. shim ¼-in. wide in the front main bearing and a 0.004-in. shim ⅛ in. wide in the front cam bearing of the right crankcase. Set the crankshaft and camshaft in position in the right crankcase resting over the shims installed. Assemble the left crankcase over the right crankcase and tighten it in position. If the crankshaft or camshaft can easily be turned by hand, the clearance between the bearing and shaft is too great and replacement of the bearing is necessary. If either shaft cannot be turned, the bearing and journal fit can then be determined by disassembling the cases and inserting a thinner shim between the shaft and bearing that will allow a slight movement of the shaft when the cases are assembled. Do not rotate the shaft more than 10 deg. when a shim is installed or the bearing surface may be damaged. Each bearing should be checked in a similar manner.

Check the crankshaft for runout at the center main bearing location by using a dial indicator with the shaft rotated on V-blocks or between centers. Check wear on the crankshaft and camshaft bearing surfaces with micrometers. Determine the clearance between the bearings and shafts. If it exceeds the maximum permissible in the list, new bearings must be installed. If the bearings or bearing surfaces are rough, scratched, or scored and require polishing, the inspection for clearance should not be made until such repair work has been completed.

Check the wear of the connecting rod bearings (big end) and of the connecting rod bearing surfaces on the crankshaft and determine the clearance

in the manner just described. If the maximum permissible clearance is exceeded, the connecting rods should be replaced with rods that will allow the proper clearance.

Inspect the inside of the cylinder barrels for scoring. With a dial indicator, check for out-of-roundness, taper, and wear.

Inspect each cylinder head for cracks, particularly in the valve guide bosses and around the valve ports, and for cracked and broken fins. Using a plug gage, check the inside diameter of the valve guides for wear and proper clearance with the valve stems.

Check the valve springs for tension. Correct limits will be found in table of clearances, on page 184.

The pistons should be inspected for cracks, scores, and corrosion. A suggested method of checking them for cracks by sound is to support the piston head by the finger tips and tap the opposite sides of the skirt with a wooden handle. Using standard piston rings or a gage, check the ring grooves and lands for proper width. *Piston rings should be replaced at each overhaul.* If the cylinder barrels have been reground or if the piston ring grooves have been remachined, care should be taken to use proper oversize piston rings.

Overhauling the Engines.—The methods shown have been suggested by the makers, and the tools and fixtures can be obtained from the Lycoming Division of the Aviation Manufacturing Corp., Williamsport, Pa.

Repairing the Engines.—Detailed methods of making repairs are given on the pages that follow.

1. No repair operations should be attempted unless suitable tools and equipment are available.
2. Slightly damaged threads should be dressed with proper thread chasers or by the careful use of a fine file.
3. Studs are not to be removed unless replacement is necessary. Such stud replacements should be made with oversize studs. When replacing studs, coat the threads with a 50–50 per cent mixture of white lead and oil prior to driving studs.
4. Gear teeth that are slightly galled, nicked, or burred should be dressed by careful hand stoning and thereafter polished with crocus cloth.
5. Any part found cracked should be replaced unless an unstressed part can be properly repaired by welding without further damage to, or distortion of, the part.
6. Such damage to finished surfaces as corrosion, scores, nicks, burrs, and roughness should be repaired by careful hand stoning, using a fine stone and gasoline, and by polishing with crocus cloth and gasoline.

When connecting rod bearings are worn beyond a safe running condition, it is best to return them to the factory, or to an authorized service station, to be exchanged for new ones.

Reaming the Crankcase.—When a used half crankcase, left or right, is fitted to a new half crankcase, the cam and crankshaft bearing bores in the cylinder crankcase assembly must be reamed for 0.010 in. oversize bearings. To do this bolt used and new half cases together using crankcase through bolts and cap screws, and tighten them securely in place. Remove the two $\frac{5}{16}$-in. magneto mounting studs from the rear of the case. Mount the crankcase assembly in a good fixture. Place the crankshaft aligning bar through the fixture and through the crankshaft bearing bores in the crankcase. Place a short camshaft aligning bar through the mixture and through the rear camshaft bearing.

Tighten four jackscrews on the fixture so that the ends of the screws rest evenly against the crankcase. Assemble the reamer and mount it in the spindle on the horizontal boring machine. Remove the short camshaft aligning bar and align the boring bar with the camshaft bearing bores. Ream through the case. Remove the reamer bar and place the long camshaft aligning bar in the holes just bored. Assemble reamers for the crankshaft bearings and mount in the boring machine spindle. Remove the crankshaft aligning bar and align the reamer bar with the crankshaft bearing bores. Bore through the case. Remove the long camshaft aligning bar and remove the case from the fixture. Check all bores with proper

Assembly.—Each part should be thoroughly clean and free from all foreign matter prior to assembly. Particular care should be taken to see that no metal particles such as ends of cotter pins, locked wire, etc., fall into the engine. New lock wire, 0.040 in. diam., is recommended for use in assembly. New gaskets, packing, lock washers, and cotter pins should also be used.

As each steel part is assembled it should be given a thin coat of clean engine oil to provide lubrication and to prevent corrosion. Each bearing surface of the operating parts should also be given a coating of clean engine oil prior to the assembly of parts.

The assembly of a geared crankshaft is seen in Fig. 8. This shows two of the counterweights in place. The other two weights are mounted on the machined ears directly below those in place.

Pistons and Rings.—Assemble piston rings on all pistons. At the same time check for proper clearance between the piston rings and grooves. The oil ring should be put on the piston first, then the two compression rings. The scraper ring is put on the bottom of the piston with the bevel edge of the ring toward the bottom of the piston.

Assemble the connecting rods and piston pins in each piston assembly. Each piston is stamped with its cylinder number on the piston pin boss and each connecting rod is stamped with its cylinder number on the end of the bearing cap. Connecting rods are to be assembled in the pistons so that when installed in the crankcase the numbers on the connecting rods are upward, or toward the top of the engine, and the numbers on the pistons are forward, or toward the propeller end. Piston pins are not numbered and are interchangeable. Place piston pin plugs in each end of piston pins. Assemble connecting rod bolts through the upper bearing cap of each rod, being sure that the flat side of the bolt head fits properly against the side of the connecting rod.

The crankcase right half, cylinders 2 and 4, is assembled first. Place the bearing end of connecting rod 2 through top of cylinder barrel 2 and, using the piston ring compressor to compress the piston rings, assemble the piston into the cylinder barrel. Place the piston so that the top of the head is just below the flange surface of the cylinder barrel. Assemble connecting rod 4 and piston in cylinder 4 in like manner.

Assemble the right crankshaft front bearing in the recess provided in the right crankcase so that the lip on the bearing enters the slot in the crankcase, and the oil holes in the bearing line up with the oil holes in the crankcase. Press the bearing into position to the bottom of the bearing recess. In the same way assemble the right crankshaft center and rear bearings in the recess provided in the right crankcase. The right crankshaft bearings can be distinguished from the left ones by the fact that only the right

bearings have oil holes to provide lubrication to the crankshaft journals. Each bearing can be installed in one position only.

Install the camshaft bearings in the right crankcase so that the lip on each bearing enters the slot provided in the bearing recess. The camshaft bearings for the right and left crankcases are identical.

Place four valve tappet assemblies in the right crankcase.

Install three oil seal rings in the recess provided at the base of the three studs in the right crankcase and one oil seal ring in the recess provided around the bolt hole in the left crankcase.

Install a front crankcase oil seal in the recess provided on each side of the front crankshaft bearing. Be sure that the seals are slightly raised above the surface of the crankcase when pressed into position.

Place the crankshaft oil seal around the crankshaft just back of the propeller hub flange.

With the right crankcase resting on top of the cylinders on the bench, install the crankshaft so that its oil seal fits in the groove in the crankcase. The crankshaft journals rest in the crankshaft bearings, and the crankpins engage with the connecting rod upper bearings in cylinders 2 and 4. Assemble the lower bearing caps on the connecting rods around the crankpins, being sure that the numbers on the connecting rod caps coincide and are toward the top of the engine. Assemble ⅜-in. slotted nuts on each connecting rod bolt and tighten. Secure the nuts with cotter pins.

Assemble the left crankshaft front bearing in the left crankcase so that the lip on the bearing enters the slot provided in the bearing recess. In like manner assemble the left crankshaft center and the rear bearings in the left crankcase. Place four valve tappet assemblies in the left crankcase.

Place the right crankcase on its side on the bench and assemble the left crankcase over the bolts of the right crankcase, being sure that all assembled parts remain in their proper positions. Raise the crankcase so that the ends of cylinders 2 and 4 are resting on the bench and, using a wooden or fiber mallet, tap the cases into position. Attach the bolts and nuts holding the right and left crankcases together and tighten them evenly until tight. The three screws in the bottom of the crankcase at the camshaft support are to be locked with wire. The two nuts on the studs inside the crankcase in the rear are also to be locked with wire, as are the two nuts on the studs in front of cylinder 3. The nut on the stud in front of cylinder 1 and the bolt through the left crankcase at the propeller end should be locked together with wire, as well as two bolts through the right crankcase at the propeller end.

Using a regular piston ring compressor assemble pistons 1 and 3 with the piston pins, piston pin plugs, and connecting rods through the top of cylinder barrels 1 and 3. See that the connecting rod upper bearings engage the crankpins and the number on the rod is toward the top of the engine. Assemble the bearing caps and ⅜-in. slotted nuts over the connecting rod bolts. Tighten the nuts and lock with cotter pins. Be sure that the numbers on the connecting rods and bearing caps coincide.

Assemble the crankshaft gear over the end of the crankshaft so that the pilot diameter on the inside of the gear fits over the crankshaft, and the dowel in the crankshaft enters the dowel hole in the gear. Tighten the gear in place using four ¼-in. screws and lock the screws together with locked wire.

On A3 engines, assemble the starter jaw on the crankshaft gear. Tighten the jaw using a 1¼-in. hex wrench, at the same time hold the crankshaft

by placing a wooden block between the crankshaft throw and the crankcase. Assemble the camshaft gear over the end of the camshaft so that the pilot diameter on the inside of the gear fits over the camshaft and the dowel in the camshaft enters the dowel hole in the gear.

Timing the Cam.—To time the cam, the camshaft gear is meshed with the crankshaft gear so that the marked tooth on the camshaft gear meshes *between* the two marked teeth on the crankshaft gear. Place the oil pump drive plate in the hole provided in the camshaft gear, assemble two gear lock plates over the gear, and tighten using four ¼-in. screws. Lock the screws in place by bending the end of the lock plate over hex of screws. Check for proper backlash between the gears.

Assemble the tachometer shaft seal in the shaft housing boss. *A2 and A3 engines require a tachometer shaft seal washer behind the seal.* See that the oil pump idler shaft is properly mounted in the accessory housing and assemble the oil pump idler gear over the shaft. Place the oil pump shaft retaining ring in the groove on the shaft, place a Woodruff key in the slot in the oil pump and the tachometer drive shaft and assemble the oil pump drive gear over the shaft and key. Place the oil pump and tachometer drive shaft assembly in the accessory housing so that the oil pump drive gear meshes with the oil pump idler gear and the end of the shaft enters through the tachometer shaft mounting boss on the accessory housing. Place the oil pump cover over the gears and assemble the two oil pump cover lock plates with four ¼-in. screws over the cover, tighten the screws, and lock with the lock plate. Check the gears for free operation.

Assemble the oil relief plunger, spring, necessary washers, and adjusting screw in the accessory housing and lock the adjusting screw with lock wire by passing the wire one turn around the tachometer connection boss.

Use a nonhardening gasket sealing compound on the accessory housing gasket and assemble the accessory housing with the gasket on the rear of the crankcase so that the oil pump and tachometer drive of the shaft assembly fit in the oil pump drive plate in the camshaft gear. *On A3 engines, see that the generator idler gear meshes properly with the crankshaft gear.* Tighten the accessory housing in place, using 5⁄16-in. plain washers, shakeproof washers, and screws. *On A3 engines, check the backlash between the generator idler gear and the crankshaft gear.*

On A3 engines, place a seal in the groove on the generator idler gear pin. Place the generator idler gear in the accessory housing, between the bores for the idler pin, so that the large diameter end of the gear hub is toward the rear of the housing. Place the idler gear pin, with the tapped puller screw hole outward, in the bore provided and through the hub of the idler gear until the end of the pin is flush with the housing.

Assemble the oil strainer assembly in the oil sump and attach it with six ¼-in. plain washers, shake-proof lock washers, and screws. *On A2 and A3 engines,* if the fuel pump is used, place the fuel pump plunger, with a circlip in the groove, in the fuel pump plunger bushing at the rear of the sump.

Apply a gasket sealing compound to the oil sump gasket and assemble the sump with gasket to the bottom of the crankcase over four ¼-in. studs on the bottom of the accessory housing. Attach the sump to the crankcase, using ¼-in. plain washers, shakeproof washers, and slotted screws. Plain nuts are used on the accessory housing studs. Install the oil sump drain plug in the bottom of the oil sump.

Cylinder Heads.—Install the intake and exhaust valves in the cylinder head assembly. Place the cylinder head over a suitable block to hold the

valves against the seats and install a valve stem circlip on each valve. Place a valve spring lower seat, valve spring, and valve spring upper seat over each valve stem. Insert a bar through the valve rocker shaft bosses and, using a valve spring compressor, compress the valves and install valve keys over the valve stems inside the valve spring upper seats. Assemble valve adjusting screws in the rocker arms and install hex huts over the screws. Place a valve rocker shaft washer on each side of the intake and exhaust rocker arms and install rocker arms with washers in the cylinder head. Assemble the valve rocker shaft through the cylinder head supports, valve rockers, and valve rocker washers. Place a valve rocker shaft plug gasket over the valve rocker shaft plug and assemble the plug with gasket in the rocker shaft boss. Make sure that the gaskets seat properly against the cylinder head to prevent any possibility of an oil leak. Safety plug through the locked wire hole at the side of the boss, using lock wire. Place a shroud tube seal in the crankcase at each valve tappet opening and in each cylinder head at the valve adjusting screw opening.

Assemble a push rod assembly in each push rod shroud tube.

Push rods and shroud tubes must be assembled on the engine at the same time as the cylinder heads. Place a cylinder head inner gasket in the cylinder counterbore and two cylinder head outer gaskets over the cylinder head studs and assemble the head with gaskets on the cylinder barrel flange. At the same time enter the ends of the push rods against the valve tappets and valve rocker arm adjusting screws and enter the shroud tube seals. Assemble $\frac{5}{16}$-in. shakeproof lock washers and plain nuts on the cylinder head studs and tighten them evenly using the box wrench.

Install an intake pipe hose with clamps on each intake pipe connection at the cylinder head and on the straight end of each intake pipe. Assemble the intake pipe to the engine by sliding the cylinder head end of the pipe inside the hose attached to the intake pipe connection, then slide the hose on the straight end of the intake pipe over the connection at the oil sump. Tighten the hose clamps at each end of the hose.

The firing order of the engine is 1-3-2-4.

Adjust the valve clearances to 0.015 in., starting with cylinder 1. Turn the crankshaft in the direction of rotation until the piston of cylinder 1 is at top center on the firing stroke when both valves will be closed. Using a 0.015 in. thickness gage between the valve rocker and valve tip, turn the adjusting screw with a screw driver until a drag is felt on the feeler gage. Hold the adjusting screw with the screw driver and tighten the hex nut. Recheck the valve clearance after tightening. In the same manner, adjust the valve clearances of the balance of the cylinders. Place rocker box cover gaskets over the rocker box cover studs on the cylinder heads and install covers with gaskets on the cylinder heads. Tighten the covers, using No. 10 plain washers and plain nuts.

To Time and Install the Magneto.—Turn the crankshaft in the direction of rotation until cylinder 1 is on the firing stroke. Bring the piston of cylinder 1 to the top dead center. Sight along the crankcase from the propeller hub rear flange, until the scribed mark on the flange stamped "TC 1" lines up with the center line of the engine at the crankcase parting line.

With the crankcase cover removed, an accurate method of checking the timing marks is to lay a straightedge along the crankcase parting line from the rear to the front of the engine and align with the timing marks.

Turn the crankshaft backward a quarter turn, then forward until the correct timing mark lines up with the crankcase parting line. (For the correct timing of the various models refer to page 162.) This position is the firing ... of the magneto or magnetos. See that the magneto coupling on A1 engines and that the magneto gears on A2 and A3 engines are properly secured to each magneto shaft. Follow the directions on page 178. Rotate the magneto drive shaft until the timing mark on the chamfered tooth of the gear and timing pointer are opposite each other as seen through the timing window in the magneto cover. Place a magneto gasket over the magneto pad on the accessory housing and install the magneto on studs over the gasket so that, on A1 engines, the magneto coupling fits into position in the crankshaft gear, and on A2 and A3 engines the magneto gears mesh with the camshaft gear. Place a piece of thin cellophane between the contact points of the magneto and, pulling lightly on the cellophane, turn the magneto through the range provided in the slots of the mounting flange against the direction of rotation *until the cellophane slips.*

The contact points are now just beginning to open. Assemble 5/16-in. plain washers, shakeproof lock washers, and nuts on the magneto mounting studs and tighten. Check the timing by turning the crankshaft backward slightly, then forward until the cellophane between the contact points slips. The correct timing mark on the hub flange should now be in line with the crankcase parting line. On dual ignition engines both magnetos turn in the same direction and must be synchronized.

Apply a gasket sealing compound to the crankcase cover gasket and assemble the cover with gasket on top of the crankcase. Attach the cover to the crankcase, using 1/4-in. plain washers, shakeproof lock washers, and screws. When tightening screws, all of them should be started in the crankcase and the two middle screws, one on each side of the cover, should be tightened first, then the other screws from the middle toward the ends of the cover. This will prevent warping of the cover and the possibility of oil leaks.

Install spark plugs with gaskets in each cylinder, and tighten the plugs.

Assemble cylinder baffles over the cylinders so that the raised end of each baffle is toward the front of the engine and attach to the crankcase cover and cylinder head. Be sure the baffles are not bent or damaged and are at the proper height above the cylinder fins.

Install the ignition cables, of lengths shown in Tables 2 and 3, to the distributor terminals in the main cover of the magneto in proper position. Attach cable clips to the crankcase cover screws and attach cable terminals to the spark plugs as shown on the Installation Drawings, page 168. The magneto distributor terminals are numbered in accordance with the firing order of the magneto, that is, 1-2-3-4. Since the firing order of the engine is 1-3-2-4, magneto wire 1 leads to cylinder 1, wire 2 to cylinder 3, wire 3 to cylinder 2, and wire 4 to cylinder 4. On A2 and A3 engines, the right magneto fires the rear plugs in each cylinder and the left magneto fires the front plugs. As cylinder heads 1 and 4 are identical, and 2 and 3 are identical, *but on opposite sides of the cylinder*, each magneto fires over two intake valves and two exhaust valves.

Assemble the rocker box vent tubes and fittings from the top of each cylinder head to the rear of the crankcase cover.

Beginning with engine No. 489, the external rocker box venting system, consisting of tubes from the cylinder heads to crankcase cover, was replaced by an entirely new internal venting system which allows the rocker boxes

to vent directly into the crankcase through one shroud tube, while oil is fed to the valve action through the other shroud tube. Care should be taken that parts are properly replaced to assure that the venting system functions properly.

If a starter or generator is used on A3 engines, assemble the gasket over the mounting pad and install the starter or generator over the studs and tighten them using 5⁄16-in. plain washers, shakeproof lock washers, and plain nuts.

Raise the engine from the bench, using a hoist attached to a cable passed around the cylinder barrels close to the crankcase. Attach the carburetor with carburetor gasket to the studs on the bottom of the crankcase. Assemble ¼-in. plain washers and castellated nuts on the studs and tighten. Lock the nuts in pairs using wire.

Attach the carburetor air intake to the carburetor using ¼-in. plain washers, shakeproof lockwashers, and cap screws.

Assemble the exhaust pipe clamps to the exhaust stacks and install stacks at the cylinder exhaust outlet tubes and tighten the clamps.

Table 2.—Lengths of Ignition Cables for O-145 Engines

	Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Total length
Single-ignition engines	23 in.	22 in.	22 in.	20 in.	7 ft. 3 in.
Dual ignition engines:					
Front plugs	28 in.	30 in.	21 in.	23 in.	16 ft. 11 in.
Rear plugs	27 in.	24 in.	27 in.	23 in.	

Table 3.—Length of Ignition Cables for GO-145 Engines

	Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Total length
Single ignition engines	25.50 in.	26.50 in.	26.50 in.	23.00 in.	8 ft. 5.50 in.
Dual ignition engines:					
Front plugs	31.0 in.	35.0 in.	25.5 in.	29.0 in.	19 ft. 10 in.
Rear plugs	32.0 in.	26.50 in.	32.0 in.	27.0 in.	

Testing after Repair.—Following the assembly of the engine after repair, it is essential that it be properly run in on a test stand before flight. Install a test club or modified flight propeller which will provide adequate cooling and permit the engine to run at rated r.p.m. at full throttle.

After the engine is started, a speed of 750 r.p.m. should be maintained for 5 min.; then increase to 1,000 r.p.m. until normal operating conditions are obtained. Continue the test in accordance with the following list:

R.p.m.	A Series, min.	B Series, min.	C Series, min.
1,000	30	30	30
1,100	30	30	30
1,200	30	30	30
1,300	30	30	30
1,400	30	30	30
1,500	30	30	30
1,600	30	30	30
1,700	30	30	30
1,800	30	30	30
1,900	20	20	20
2,000	20	20	20
2,100	20	20	20
2,200	....	20	20
2,300	....	20	20
2,400	....	20	20
Full throttle consumption for ½ pt. fuel at rated r.p.m.	53.6 sec.	43.4 sec.	39.8 sec.

Table 4.—Oversize Parts

Part no.	Part name	Oversize
45127-X	Stud—crankcase—front	+0.003
45128-X	Stud—crankcase—center upper	+0.003
45129-X	Stud—crankcase—center lower	+0.003
45130-X	Stud—crankcase—rear	+0.003
45135-X	Stud—magneto	+0.003
45234-X	Bearing—crankshaft—front—left	−0.020 I.D.
45234-XA	Bearing—crankshaft—front—left	+0.010 O.D. −0.020 I.D.
45234-XB	Bearing—crankshaft—front—left	−0.010 I.D.
45234-XC	Bearing—crankshaft—front—left	−0.003 I.D.
45234-XD	Bearing—crankshaft—front—left	+0.010 O.D. −0.010 I.D.
45234-XE	Bearing—crankshaft—front—left	+0.010 O.D. −0.003 I.D.
45234-XF	Bearing—crankshaft—front—left	+0.010 O.D.
45235-X	Bearing—crankshaft—front—right	−0.020 I.D.
45235-XA	Bearing—crankshaft—front—right	+0.010 O.D. −0.020 I.D.
45235-XB	Bearing—crankshaft—front—right	−0.010 I.D.
45235-XC	Bearing—crankshaft—front—right	−0.003 I.D.
45235-XD	Bearing—crankshaft—front—right	+0.010 O.D. −0.010 I.D.
45235-XE	Bearing—crankshaft—front—right	+0.010 O.D. −0.003 I.D.
45235-XF	Bearing—crankshaft—front—right	+0.010 O.D.
45277-X	Bearing—camshaft	−0.020 I.D.
45277-XA	Bearing—camshaft	+0.010 O.D. −0.020 I.D.
45277-XB	Bearing—camshaft	−0.010 I.D.
45277-XC	Bearing—camshaft	−0.003 I.D.
45277-XD	Bearing—camshaft	+0.010 O.D. −0.010 I.D.
45277-XE	Bearing—camshaft	+0.010 O.D. −0.003 I.D.
45277-XF	Bearing—camshaft	+0.010 O.D.
45290-X	Bearing—crankshaft—center and rear—right	−0.020 I.D.
45290-XA	Bearing—crankshaft—center and rear—right	+0.010 O.D. −0.020 I.D.
45290-XB	Bearing—crankshaft—center and rear—right	−0.010 I.D.
45290-XC	Bearing—crankshaft—center and rear—right	−0.003 I.D.
45290-XD	Bearing—crankshaft—center and rear—right	+0.010 O.D. −0.010 I.D.
45290-XE	Bearing—crankshaft—center and rear—right	+0.010 O.D. −0.003 I.D.
45290-XF	Bearing—crankshaft—center and rear—right	+0.010 O.D.
45291-X	Bearing—crankshaft—center and rear—left	−0.020 I.D.
45291-XA	Bearing—crankshaft—center and rear—left	+0.010 O.D. −0.020 I.D.
45291-XB	Bearing—crankshaft—center and rear—left	−0.010 I.D.
45291-XC	Bearing—crankshaft—center and rear—left	−0.003 I.D.
45291-XD	Bearing—crankshaft—center and rear—left	+0.010 O.D. −0.010 I.D.
45291-XE	Bearing—crankshaft—center and rear—left	+0.010 O.D. −0.003 I.D.
45291-XF	Bearing—crankshaft—center and rear—left	+0.010 O.D.
45310-X	Bearing—connecting rod	−0.0025
45310-XA	Bearing—connecting rod	−0.005
45310-XB	Bearing—connecting rod	−0.010
45310-XC	Bearing—connecting rod	−0.020
45311-X	Bearing—connecting rod	−0.0025
45311-XA	Bearing—connecting rod	−0.005
45311-XB	Bearing—connecting rod	−0.010
45311-XC	Bearing—connecting rod	−0.020
45339-X	Piston—(compression 6.5 to 1)	+0.010
45339-XA	Piston—(compression 6.5 to 1)	+0.020
45340-X	Piston—(compression 5.65 to 1)	+0.010
45340-XA	Piston—(compression 5.65 to 1)	+0.020
45341-X	Ring—piston—(compression)	+0.010 Diam.
45341-XA	Ring—piston—(compression)	+0.020 Diam.
45342-X	Ring—piston—(oil)	+0.010 Diam.
45342-XA	Ring—piston—(oil)	+0.020 Diam.
45343-X	Ring—piston—(scraper)	+0.010 Diam.

Table 4.—Oversize Parts (*Continued*)

Part no.	Part name	Oversize
45343-XA	Ring—piston—(scraper)	+0.020 Diam.
45344-X	Pin—piston	+0.005
45375-X	Tappet assembly—valve	+0.005
45375-XA	Tappet assembly—valve	+0.010
45433-X	Seat—valves—(intake)	+0.005
45433-XA	Seat—valves—(intake)	+0.010
45433-XB	Seat—valves—(intake)	+0.015
45433-XC	Seat—valves—(intake)	+0.020
45433-XD	Seat—valves—(intake)	+0.025
45433-XE	Seat—valves—(intake)	+0.050
45435-X	Stud—rocker box cover	+0.005
45452-X	Stud—cylinder head	+0.005
45456-X	Guide—valve	+0.005
45456-XA	Guide—valve	+0.010
45465-X	Seat—valves (exhaust)	+0.005
45465-XA	Seat—valves (exhaust)	+0.010
45465-XB	Seat—valves (exhaust)	+0.015
45465-XC	Seat—valves (exhaust)	+0.020
45465-XD	Seat—valves (exhaust)	+0.025
45465-XE	Seat—valves (exhaust)	+0.050
45527-X	Stud ¼-20 × 1.13	+0.005
45611-X	Stud ¼-20 × 1.38	+0.005

After the completion of the run-in period, check the engine for acceleration and fuel consumption at full throttle and rated r.p.m. The desired length of time necessary to consume ½ pt. of fuel is shown in the above table and should be held within a limit of ±2 sec. **Caution.** When making fuel flow run at full throttle and rated r.p.m. on the B and C Series engines they must *not be run more than* 2 *min. at a time.* If it is necessary to repeat the fuel check, allow the engine to cool after each run.

Following the run-in period, gradually reduce the engine speed and adjust the idling speed to 400 r.p.m. Drain the oil in the sump and check the drained oil carefully for the accumulation of any foreign materials.

Make a visual inspection of the reciprocating parts of the engine by removing the crankcase cover. Inspect each cylinder wall for its general condition.

Check all nuts and screws for proper tightness, particularly the cylinder head hold-down nuts, *and recheck valve clearances to* 0.015 *in. when the engine is cold before installing the engine in the airplane.*

Installation.—Hoist the engine by means of a sling passed under the cylinder barrels on each side of the crankcase and lower it carefully in the engine mount of the airplane. It may be necessary with some engine mounts to remove the intake pipes from the engine before it is installed in the mount. Intake pipes are to be installed in accordance with instructions. A screw driver or similar tool must not be used in removing and installing intake pipes which might damage the intake pipe hose connections. With a new rubber washer placed each side of the engine mounting bolt boss, and with leather bushing wrapped around each bolt, attach the engine to the mount using ⅜-in. bolts, plain washers, and castellated nuts. See Installation Drawings, page 168, for the method of mounting the engine. Tighten the nuts and lock them with cotter pins. Avoid drawing the nuts too tight as this will force the washers out of their proper position.

Connect the ground wire to the ground terminal on the magneto. Install the oil temperature bulb in the crankcase. Connect primer lines from the primer pump to the cylinders. Place the tachometer shaft gland over the tachometer shaft seal and attach the tachometer cable to the connection

on the accessory housing. Connect the oil pressure line to the oil pressure connection at the acc housing. Connect the starter and generator connections and attacl el lines to the fuel pump and to the carburetor.

Attach the throttle hrottle lever at the carburetor and see that full and positive movement the throttle control is permitted.

Turn the crankshaft so "28° ADV" marked on the propeller hub rear flange lines up with the crankcase parting line and assemble the propeller over the pilot on the propeller hub rear flange in a horizontal position. This position places the blade in a convenient location to facilitate starting the engine by hand. Place the propeller hub front flange on the propeller hub and attach to the crankshaft with six ⅜-in. bolts. Safety the bolts together with lock wire.

Fill the oil sump with 4 qt. of the proper grade of oil and fill the fuel tank with 73 octane aviation gasoline. See that the cylinder baffles and engi cowling are properly secured.

Table 5.—Service Fits and Clearances

	Min.	Max.	Max. allowable
Main bearings on crankshaft journal, front, center, and rear	0.0025L	0.0040L	0.006L*
Valve tappets in guides	0.0005L	0.0015L	0.004L
Rocker arms on shafts	0.0015L	0.0022L	0.005L
Valve stems in guides	0.0025L	0.0035L	0.0075L
Connecting rod on crankpin	0.0015L	0.0030L	0.005L
Piston pin:			
In connecting rod	0.0003L	0.0010L	0.0025L
In piston	0.0001T	0.0004L	0.0025L
Piston ring, side clearance:			
No. 1 compression	0.0035L	0.0050L	0.008L
No. 2 compression	0.0025L	0.0040L	0.007L
No. 3 oil regulating	0.0020L	0.0035L	0.006L
No. 4 oil scraper	0.0010L	0.0025L	0.005L
Piston ring cap	0.009	0.014	0.025
Piston skirt and cylinder	0.0090L	0.0115L	0.017L
Camshaft in cam bearings	0.0010L	0.0026L	0.004L
Crankshaft and front main bearing, end play	0.005L	0.010L	0.015L
Backlash—cam gears	0.002	0.004	0.015
Crankshaft runout—center main journal	0.000	0.003	0.006
Valve springs compressed:			
1¼ in., A Series	38 lb.	42 lb.	35 lb., min.
1⁹⁄₁₆ in., A Series	17 lb.	21 lb.	15 lb., min.
1³⁄₁₆ in., B Series	60 lb.	64 lb.	55 lb., min.
1⁹⁄₁₆ in., B Series	18 lb.	22 lb.	16 lb., min.
Valve springs, C Series:			
Inner spring compressed 1¹³⁄₃₂ in.	11 lb.	16 lb.	9 lb., min.
Inner spring compressed 1 in.	20 lb.	25 lb.	18 lb., min.
Outer spring compressed 1⁹⁄₁₆ in.	29 lb.	34 lb.	26 lb., min.
Outer spring compressed 1⁵⁄₁₆ in.	52 lb.	57 lb.	48 lb., min.

* The letters L and T mean "loose" and

Warm up the engine for about 5 min. at 1,000 r.p.m. and check full throttle operation. Adjust the idling speed to 400 r.p.m. Shut off the engine and check all mounting bolts and engine connections for proper security. Also check the fuel and oil lines and connections for leakage.

GEARED LYCOMING ENGINES

Series GO-145 are geared down from engine to propelle The general specifications of these engines are given in Table 6.

These engines are inspected, disassembled, repaired, reassembled, and tested in the same general way as the models O-145. The lengths of

Table 6.—General Specifications of Model GO-145 Engines

	GO-145-C1	GO-145-C2	GO-145-C3
Engine type certificate	210	210	210
Rated horsepower	75	75	75
Propeller reduction gear ratio	27 to 17	27 to 17	27 to 17
Rated r.p.m.:			
Engine	3,200	3,200	3,200
Propeller	2,015	2,015	2,015
Cruising r.p.m.:			
Engine	2,900	2,900	2,900
Propeller	1,826	1,826	1,826
Bore	[illegible]	3⅝	3⅝
Stroke	3½	3½	3½
Compression ratio	6.5 to 1	6.5 to 1	6.5 to 1
Piston displacement, cu. in	144.5	144.5	144.5
Head temperature—max. °F	525	525	525
Barrel temperature—max. °F	325	325	325
Oil temperature—max. °F	220	220	220
Fuel octane	73	73	73
Fuel consumption—(cruising) bhp. per hr.-lb	0.50	0.50	0.50
Oil sump capacity, qt	4 or 8	4 or 8	4 or 8
Oil pressure:			
Minimum idling, lb	15	15	15
Normal operating, lb	70–80	70–80	70–80
Crankshaft rotation—antipropeller end	Clockwise	Clockwise	Clockwise
Propeller shaft rotation—antipropeller end	Clockwise	Clockwise	Clockwise
Valve clearance—intake and exhaust cold	0.015	0.015	0.015
Spark occurs, deg. B.T.C	28	25	25
Firing order	1-3-2-4	1-3-2-4	1-3-2-4
Spark plugs:			
Edison Splidorf, 0.025 gap	HC-83	HC-83	HC-83
Champion Available, 0.025 gap	LM-3-1	LM-3-1	LM-3.1
Engine dry weight including carburetor, magneto or magnetos, and spark plugs, lb	182.50	193.0	195.0
Prop flange and baffles, lb	6.08	6.08	6.08
Engine total weight, lb	188.58	199.08	201.08
Radio shielding—added weight, lb	0.54	1.18	1.18
Carburetor—Marvel	MA-2	MA-2	MA-2
Magneto—Bendix-Scintilla SF-4L	One	Two	Two
Fuel pump—A. C. Type AT model G.P. 8897	Available	Available	Available
Generator—Eclipse Type LV-180 model 3771-1	None	None	Available
Starter—Eclipse Type E-80 model 2624-AR	None	None	Available

ignition cables are given in Table 3; service fits and clearance are shown in Table 5.

GO-145 Lycoming Engines

The Lycoming model GO-145 engines are four-cylinder, horizontally opposed, air-cooled aircraft engines with reduction gear. The gear unit is a spur type, single pinion, and internal ring gear having a reduction ratio of 27 to 17. It is rated at 75 hp. at 3,200 r.p.m. and a propeller r.p.m. of 2,015. The reduction gearing is seen in Fig. 8.

The numeral following the suffixing letter denotes the equipment on engine, that is, "1"—single ignition, "2"—dual ignition, and "3"—dual ignition with generator and starter drive. All engines can be furnished with fuel pump drive if desired.

The crankshaft is forged molybdenum steel, nitrided to produce a hard surface on the main and crankpin journals, and is equipped with double, dynamic dampeners to assure smooth operation of the engine at all speeds.

The crankshaft reduction gear and propeller shaft are forged molybdenum steel with hardened, heavy spur type teeth to ensure long life. The propeller flange is 6.00 in. in diameter, whereas, the propeller flange of the 0-145 direct-driven engines has a diameter of 5.50 in.

The magneto timing is as follows:

GO-145-C1	28 deg.
GO-145-C2, C3	25 deg.

Oil Recommendations

Summer, temperature above 40°F	S.A.E. 40
Winter, temperature below 40°F	S.A.E. 30 W

Polishing a Camshaft—Model O-145.—When a Lycoming crankshaft bearing becomes rough from any cause, the makers recommend the use of Aloxite abrasive paper, held in a modern polishing clamp, as shown in Fig. 9.

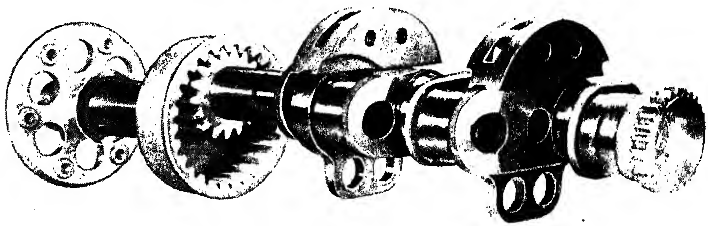


Fig. 8.—Geared crankshaft with two counterweights in place.

This clamp has two bushings, one of the proper size for the crankpins, the other for the main bearings. The makers suggest No. 5/0 Aloxite for the roughing cut, No. 7/0 for a second polish, and No. 10/0 for finishing. The paper should be 1$\frac{3}{16}$ in. wide for crankpins and 1$\frac{1}{8}$ in. wide for main journals.

With the crankshaft revolving in the lathe, the clamp is used on all the crankpins but only on the center main journal. The front and rear journals should be polished with the abrasive paper held by a piece of flat stock of proper width.

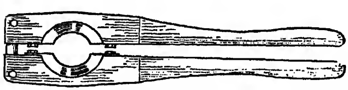


Fig. 9.—Polishing clamp for crankshaft journals.

This polishing should remove only a small amount of metal; bearings that are undersize by 0.003 in. are supplied for these cases. Should the journals be scored deeper than this, they should be reground to fit undersize bearings for 0.010 and 0.020 in. below standard.

Replacing Crankcase Studs.—Coat all studs with white lead and oil mixture before driving them into the case.

Stud drivers are simple but very necessary in replacing studs in crankcases. In the crankcase assembly the front stud should be screwed in to leave a height of 2.81 in. from the face of the case. The center *upper* stud should be 4 in., the center *lower* stud 4.19 in., the rear stud 1.19 in., the magneto stud 1.84 in.

Reaming Valve Tappet Holes.—Reamers and gages are available for tappet holes to be either 0.005 or 0.010 in. oversize. One of these should be used whenever tappet holes show signs of wear.

Removing and Replacing Spark-plug Bushings.—Place the cylinder head in a fixture and hold it in place with two $\frac{5}{16}$-in. nuts on the cylinder head studs. Put a piloted counterbore in a drill press and bore through the spark-

plug bushing, feeding by hand. The shell that remains can be removed without damaging the thread in the cylinder head. Remove the dowel.

In putting in a new bushing, heat the cylinder head in oil to about 600°F. Coat the outside of the bushing with castor oil and screw the bushing in with the bushing driver provided for that purpose. This shrinking of the bushing in place is why it must be bored out. With a No. 31 drill (0.12 in.), drill through the bushing flange and into the cylinder head casting. Drive in a dowel pin as extra precaution against loosening.

Tap the bushing for the spark plug, using a hand tap.

Removing, Replacing, and Reaming Valve Guides.—Provisions are made for reaming these holes 0.005, 0.010, or 0.020 in. oversize, with reamers that are available for this purpose.

To remove the valve guide (intake or exhaust), place the cylinder head in the fixture from which the two valve support pins have been removed, and secure it to the fixture using two $\frac{5}{16}$-in. nuts on the cylinder-head studs. Assemble the counterbore and pilot with holder and mount them in drill press spindle. Align the counterbore with the valve guide and clamp the fixture to the drill press table. Bore through the guide using hand feed. Remove the remaining shell, being careful not to damage the guide bore.

Ream the guide bore in the cylinder head before installing the new guide. Place the head in the same fixture proper on the bench and ream the guide bore for the desired oversize guide using an expansion reamer. Check the reamed hole with a plug gage. If the guide removed was 0.005 in. oversize, the guide bore must be reamed for 0.010 in. oversize guide. Check the reamed hole with two plug gage. To install a new guide in the cylinder head, heat the head in oil to 600°F. Place a small amount of castor oil on the outside of the guide and, using a drift, tap the guide into full seat. Use the proper oversize guide according to the reamed hole.

After the cylinder head has cooled to room temperature, ream the valve guide. Hand ream through the guide first using a roughing reamer, then finish to size with an expansion reamer, and check the reamed hole with a plug gage. Use the proper reamer to suit the oversize valve to be installed.

Reconditioning Valve Seats.—To remove valve seats from the cylinder head, mount the head in the fixture and fasten it with nuts on the rocker box cover studs. Counterbores are made in five oversizes: 0.010, 0.015, 0.020, 0.025, and 0.050 in. Put the proper counterbore and pilot in the drill press spindle, clamp the fixture to the table, and bore the seat to a depth of $\frac{21}{64}$ in. Remove the shell without damaging the seat bore.

Before the valve seat is replaced, the recess must be bored to the next larger oversize in the same fixture. After checking the bore with a gage, heat the cylinder head in oil to 600°F. as before, put the oversize seat on the "drift" or set so that the undercut is toward the combustion chamber when the seat is in place, and put the seat in place. Hold it in place until the cylinder head cools enough to grip the seat firmly.

Face the seat to proper height with a piloted counterbore until the top of the seat cutter just touches metal in the cylinder head. Peen the seat in place with the tool provided, rolling aluminum over against the undercut of the seat. Remove any sharp edges around the seat.

Removing Magnetos.—This requires a puller, which differs for single- and dual-ignition engines. In both cases the puller jackscrew is first backed off, then put over the end of magneto shaft so as to grip the gear, and the magneto pulled free.

Pistons and Rings.—Pistons are easily assembled in the cylinders by using a compressor, or clamp, to hold the rings while being entered in the cylinder. These clamps can be made in several ways. A ring wide enough to cover one ring and having a beveled edge inside so that rings will be closed as they enter the cylinder, answers nicely. Some use a clamp that slides back as the piston enters the cylinder.

To remove rings, they must be expanded enough to slip over the piston. For this purpose a tool is provided by the Lycoming Company, who also have a very complete tool kit. Although rings can be removed by an experienced man without an expanding tool, such a tool saves ring breakage.

LYCOMING RADIAL ENGINES

In addition to the opposed four-cylinder engines, Lycoming builds Type R-680 and Type R-530. These are static, air-cooled, radial engines with

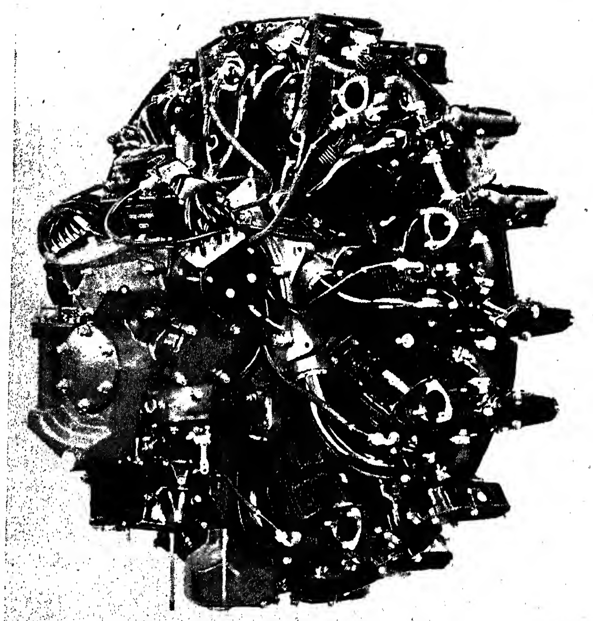


Fig. 10.—Lycoming nine-cylinder radial engine.

nine and seven cylinders, respectively. The R-680 has 215 rated hp. at 2,000 r.p.m. This Series is built in several models with horsepower ratings up to 300 at 2,300 r.p.m. The R-530D Series is from 190 hp. at 2,100 r.p.m. to 220 hp. at 2,300 r.p.m. The different horsepower is secured largely by

varying the compression and the r.p.m. of the engine. Table 7 gives details. But improved design of the cooling fins and other details have also added to the performance secured.

Whenever possible, engine parts have been made interchangeable between the seven- and nine-cylinder models. These include cylinder assemblies, piston assemblies, push rods, push rod housings, intake pipe, and oil sump.

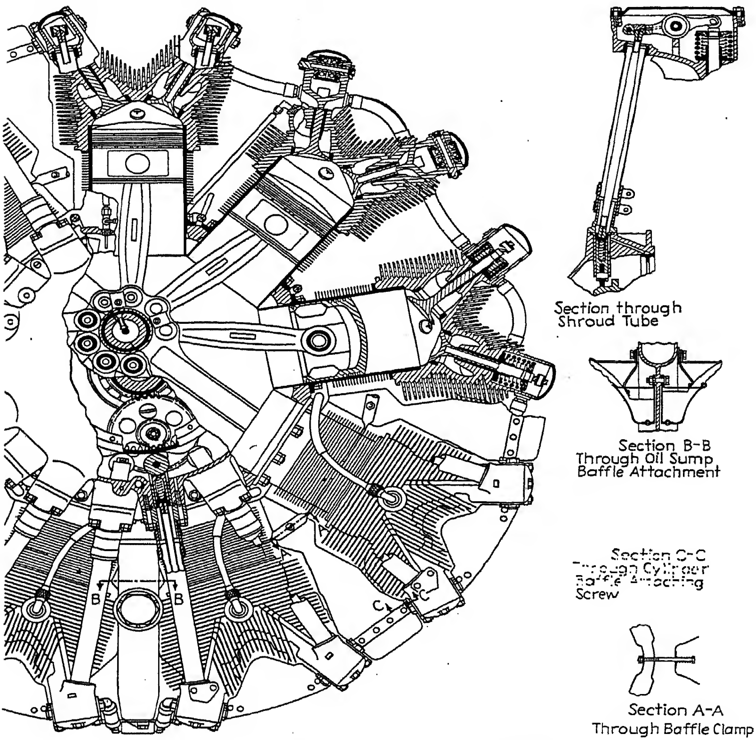


FIG. 11.—Partial section of the radial engine.

The crankcase, thrust bearing housing, crankshaft, master rod, and cam are, of course, different.

The two engines also differ in some details, such as the method of fastening the baffle plates, but the general design is, very sensibly, carried along similar lines. For this reason only the larger engine, model R-680 Series, is shown (Fig. 10). A partial section is shown in Fig. 11.

The drawings of the engines (Figs. 12 to 16) are not intended to show all construction details but to give a sufficient idea of the design and general

dimensions to make one fairly well acquainted with the type and general features. Figure 13 is of special interest with its details of the wiring and radio shielding. It can be studied to advantage. Figures 14 to 16 show the installation and Fig. 17 the oiling system. Table 7 shows the difference between the models.

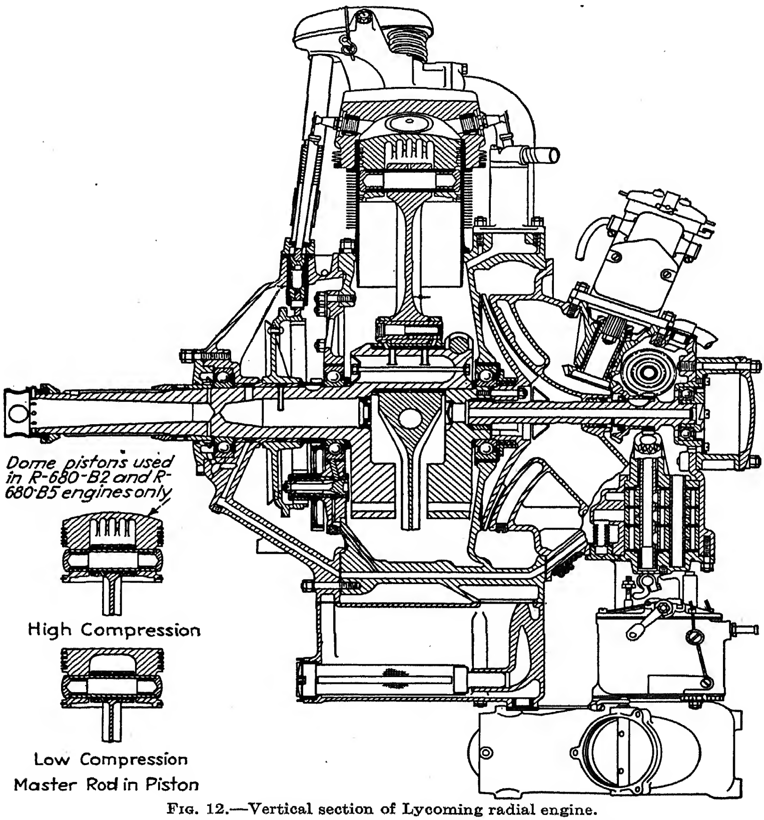
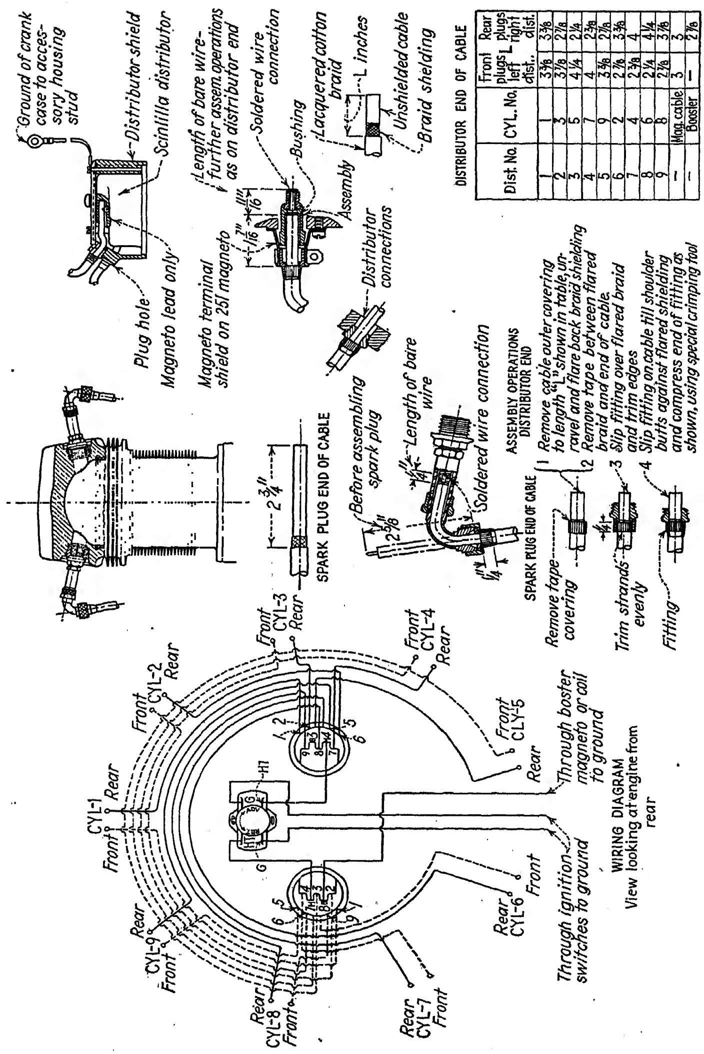


FIG. 12.—Vertical section of Lycoming radial engine.

Crankcase Sections.—The crankcase consists of four sections secured together on flanged surfaces by studs and nuts to form a rigid crankcase assembly. The thrust bearing housing (front section) and the accessory drive housing (rear section) are machined from magnesium alloy castings. Prior to the 1935 production engines, these sections were machined from aluminum alloy castings. The front main bearing plate is an aluminum



DISTRIBUTOR END OF CABLE

Dist. No.	CYL. No.	Front plugs L left dist.	Rear plugs L right dist.
1	1	3⅜	3⅜
2	3	3⅞	2⅞
3	5	4¼	2¼
4	7	4	2⅜
5	9	3⅜	2⅞
6	2	2⅞	3⅜
7	4	2⅜	4
8	6	2¼	4¼
9	8	2⅞	3⅞
—	Mag. cable	3	3
—	Booster	—	2⅞

FIG. 13.—Wiring diagram of Lycoming radial engine.

alloy forging and the main crankcase section is machined from an aluminum alloy casting. (A number of 1935 and 1936 production engines were

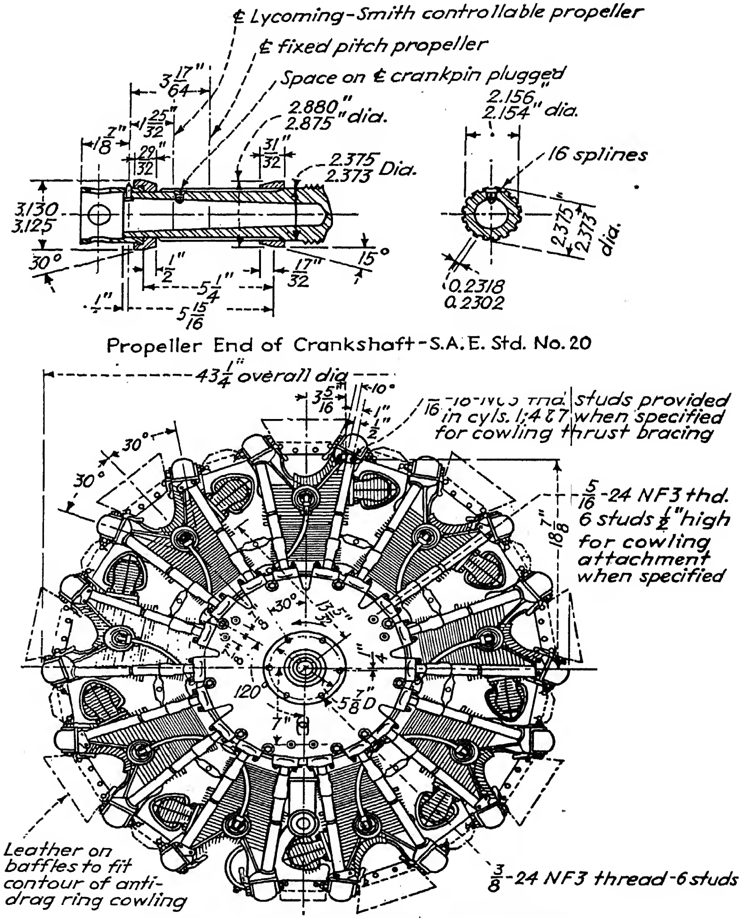


FIG. 14.—Installation drawing of Lycoming radial engine.

produced with a magnesium alloy crankcase, now discontinued.) Each of the above crankcase sections is heat-treated prior to final machining operations.

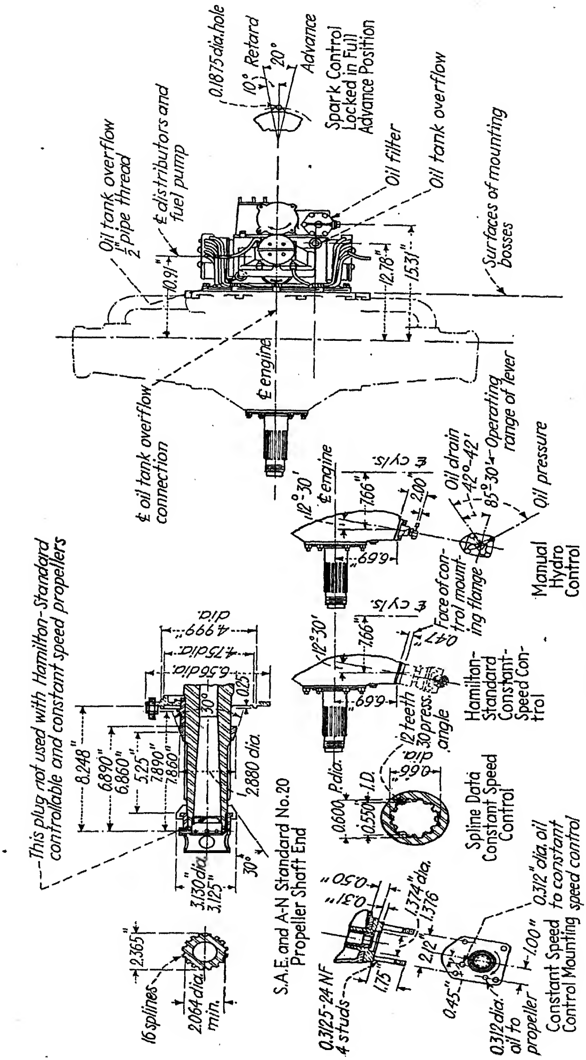


Fig. 15.—Propeller shaft details and accessories.

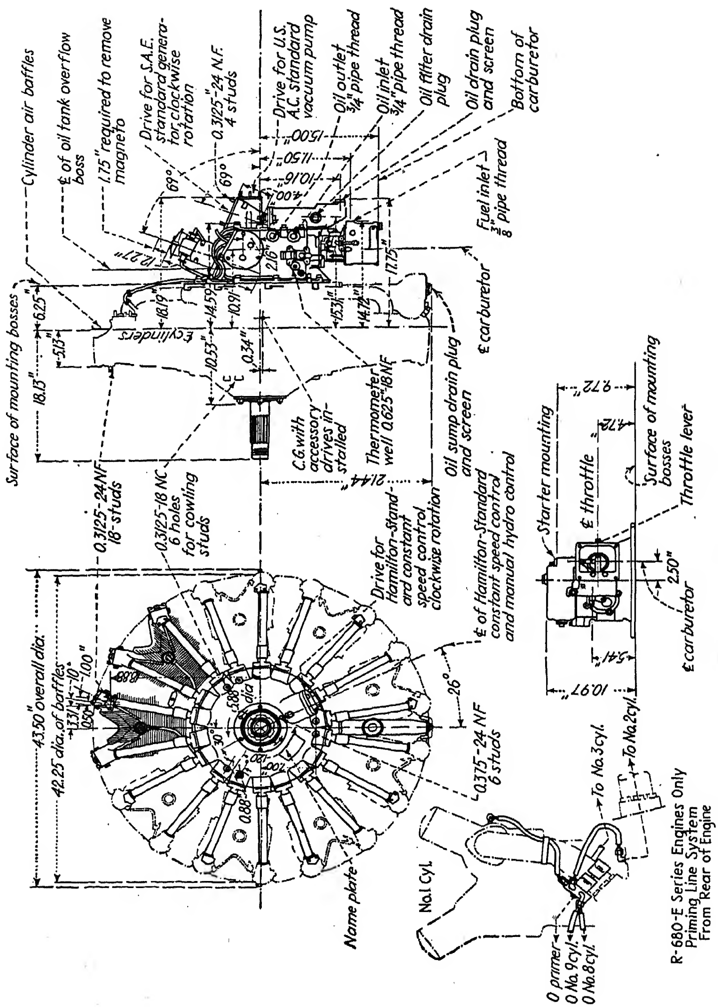


Fig. 16.—Over-all mounting dimensions.

The main crankcase provides mounting pads for the cylinders and supports the rear main bearing. The rear of the main crankcase also includes the diffuser chamber with tangential outlets for the cylinder intake pipes. Eight mounting lugs are provided on the rear circumference of this section to support the engine in the airplane structure.

The front main bearing plate, attached to the front end of the main crankcase, supports the front main bearing and the cam idler gear assembly.

The thrust bearing housing supports the propeller thrust bearing and contains the cam followers and guides. On model R-680-B Series engines, the standard thrust bearing cap may be replaced with a special cap assembly to adapt the hydropropeller control mechanism. On model R-680-D, R-680-E, and R-530-D Series engines, this section provides drilled oil

Table 7.—Lycoming Engine Model Designations

Series	Current model no.	Former model no.	Engine type certificate	Rated horsepower	Rated r.p.m.	Compression ratio
	R-680	....	42	215	2,000	5.3 to 1
R-680-B........	R-680-B2 R-680-B4 R-680-B5* R-680-B6*	R-680-2, R-680-BA R-680-4 R-680-5* R-680-6*	81 108 110 111	240 225 260* 245*	2,000 2,100 2,300* 2,300*	6.5 to 1 5.5 to 1 6.5 to 1 5.5 to 1
R-680-D........	R-680-D5	....	172	260* 245	2,300* 2,100	6.5 to 1
	R-680-D6	....	173	245* 225	2,300* 2,100	5.5 to 1
R-680-E........	R-680-E1	....	202	290* 275	2,300 2,200	6.2 to 1
	R-680-E2	....	202	280* 265	2,300 2,200	5.5 to 1
	R-680-E3	....	202	300* 285	2,300 2,200	7.0 to 1
R-530-D........	R-530-D1	....	182	220* 200	2,300 2,100	6.5 to 1
	R-530-D2	....	183	210* 190	2,300 2,100	5.5 to 1

* These engine ratings are available only with a controllable propeller for 1 min. during take-off. All other ratings listed are the normal engine ratings with fixed pitch propeller.

passages for the distribution of pressure oil to the cam followers and for the operation of hydrocontrollable propellers. Either the standard manual control lever or a constant-speed governor drive is installed on the boss provided on the front section. The governor is driven from a spur gear bolted to the cam assembly and through an intermediate gear mounted on the front wall of the thrust bearing housing. A crankshaft oil seal sleeve with two split type rings in each of three ring grooves prevents the leakage of pressure engine oil from the front crankshaft and thrust bearing housing oil passages.

The accessory drive housing, which is attached to the rear of the main crankcase, supports the following accessory equipment and the necessary drives: one Scintilla dual-vertical magneto, two independent ignition distributors, an oil pump assembly, single or dual tachometer drives, and a starter mounting. Provision is made for mounting and driving a generator,

a fuel pump, and a vacuum pump. A self-aligning ball bearing for the accessory drive shaft is supported in this crankcase component. The oil pressure relief valve assembly and the carburetor are attached to the accessory drive housing.

A starter drive housing is used on model R-680-D and R-680-E Series engines which incorporates a Cuno oil filter and provides a starter mounting.

Table 8.—General Specifications, Lycoming Radial Engines

(Applicable to all models of the Lycoming Type R-680 and R-530 aviation engines)

Type	direct drive, single row, radial, air cooled
Number of cylinders:	
Model R-680 Series	9
Model R-530 Series	7
Bore, in.	4⅝
Stroke, in.	4½
Piston displacement (cu. in.):	
Model R-680 Series	680.4
Model R-530 Series	529.2
Compression ratios (see Table 10)	
Impeller gear ratio	1 to 1
Impeller, diam., in.	12⅜
Rating (see Table 10)	
Crankshaft rotation (viewed from antipropeller end)	Clockwise
Mounting:	
Diameter of mounting bolt circle	19¼
Number of mounting bolts:	
Model R-680 Series	8
Model R-530 Series	6
Size of mounting bolts, in.	⅜
Center of gravity position (see Table 10)	
Over-all diameter and length (see Table 10)	
Ignition (see Table 10)	

Valve timing and clearance (under average operating conditions):

	R-530-D	R-680-E	R-680, R-680-B, R-680-D
Intake opens (deg. B.T.C.)	30	40	15
Intake closes (deg. A.B.C.)	60	50	45
Exhaust opens (deg. B.B.C.)	60	65	60
Exhaust closes (deg. A.T.C.)	30	25	15
Intake remains open (crankshaft deg.)	270	270	240
Exhaust remains open (crankshaft deg.)	270	270	255
Valve lift, in.	0.45	0.45	0.45
Intake and exhaust valve clearance (both valves closed, in.)	0.015	0.015	0.015

Fuel system:	
Fuel required (see Table 10)	
Fuel pressure desired (lb. per sq. in.):	
Gravity fuel system	1.5
Fuel pump system	5.0
Lubrication system:	
Oil required (AMCOR. Spec. No. 301).	Grade 120 (summer) / Grade 100 (........)
Oil consumption at full throttle (lb. per hp. hr.)	0.025
Oil pressure (lb. per sq. in.):	
Minimum idling	15
At normal r.p.m. and normal oil temperature	50–75
Minimum safe quantity of oil (in whole system), U.S. gal.	2
Desired oil temperature (in normal flight)	140°F. (60°C.)
Maximum permissible oil temperature	70°F. above outside air temperature, or 185°F. (85°C.)
Speed of oil pump (in multiples of crankshaft speed):	
Model R-680, R-680-B, and R-530-D Series engines	0.835
Model R-680-D and R-680-E Series engines	0.527

This is secured to the accessory drive housing by means of studs and nuts. The generator and vacuum pump drives are also incorporated in this housing.

Cylinders.—The cylinder assemblies are of conventional design for air-cooled engines. The cylinder barrel is machined from a carbon steel forging and heat-treated between machining operations. The cylinder head, with rocker arm supports and fins integral, is machined from an aluminum alloy

casting. The cylinder head is screwed and shrunk over the steel barrel to provide a *permanent* joint. An intake and exhaust valve seat of aluminum bronze, a hardened steel exhaust valve guide, an aluminum bronze intake valve guide, and aluminum bronze spark-plug bushings, are shrunk into the aluminum head.

Table 9.—Accessory Drives and Instrument Connections for Lycoming Radial Engines

Engine model or model series	Model R-530-D Series*	Model R-680 and R-680-B Series	Model R-680-D and R-680-E Series
Propeller shaft end—splined type	No. 20	No. 20	No. 20
Oil pressure gage connection	1/8-in. pipe thread	1/8-in. pipe thread	1/8-in. pipe thread
Oil tank vent connection	9/16-in. standard thread	9/16-in. standard thread	1/8-in. pipe thread
Starter flange and drive:			
Mounting	S.A.E. standard	S.A.E. standard	S.A.E. standard
Direction of rotation (facing drive)	Clockwise	Clockwise	Counter-clockwise
Speed (multiples of crankshaft speed)	1.00	1.00	1.00
Tachometer drive connection:			
For S.A.E. and A.C. standard drives	Single	Single	Single
Direction of rotation (facing drive)	Counter-clockwise	Counter-clockwise	Counter-clockwise
Speed (multiples of crankshaft speed)	0.50	0.50	0.50
Generator flange and drive:			
Mounting	S.A.E. standard	S.A.E. standard	S.A.E. standard
Direction of rotation (facing drive)	Counter-clockwise	Counter-clockwise	Clockwise
Speed (multiples of crankshaft speed)	1.25	1.25	1.50
Fuel pump flange and drive:			
Mounting	S.A.E. standard	S.A.E. standard	Air Corps standard
Direction of rotation (facing drive)	Counter-clockwise	Counter-clockwise	Counter-clockwise
Speed (multiples of crankshaft speed)	1.00	1.00	1.00
Vacuum pump flange and drive:			
Mounting	....	....	S.A.E. standard
Direction of rotation (facing drive)	....	....	Counter-clockwise
Speed (multiples of crankshaft speed)	....	....	1.64
Auxiliary fuel pump flange and drive:			
Mounting	....	Modified S.A.E. standard	
Direction of rotation (facing drive)	....	Clockwise	
Speed (multiples of crankshaft speed)	....	1.43	
Auxiliary vacuum pump flange and drive:			
Mounting for Eclipse No. 2932-D1A pump	....	Not standard	
Direction of rotation (facing drive)	....	Clockwise	
Speed (multiples of crankshaft speed)	....	1.00	
Constant speed governor flange and drive:			
Mounting for Hamilton-Standard governor	....	....	Model A-1
Direction of rotation (facing drive)	....	....	Clockwise
Speed (multiples of crankshaft speed)	....	....	1.04

* Also available for the R-530-D Series engines are the accessory drives of the R-680-D and R-680-E Series engines.

Cylinder Baffles.—Pressure type air baffles, or deflectors, are employed on all engines except the R-680 Series. With the use of ring cowls or "speed rings" in modern airplanes, cylinder air baffles force a high velocity flow of cooling air through the cylinder fin spaces, the forward speed of the airplane building up a positive air pressure in front of the cylinders and a negative air pressure in their rear. A maximum cooling effect on the

Table 10.—Detail Specifications

Model designation	R-680	R-680-B2	R-680-B4	R-680-B5
Approved type certificate, no.	42	81	108	110
Compression ratio	5.3 to 1	6.5 to 1	5.5 to 1	6.5 to 1
Rated speed for take-off with controllable propeller, r.p.m.		......		2,300
Rated normal speed, r.p.m.	2,000	2,000	2,100	2,000
Rated brake horsepower for take-off with controllable propeller at sea level	...			...
Rated normal brake horsepower at sea level	215	240	225	240
Center of gravity position:				
Distance forward of rear face of mounting bosses, in.	5.90	5.90	5.90	5.90
Distance below crankshaft center line, in.	0.62	0.62	0.62	0.62
Over-all diam. of engine, in.	43.25	43.25	43.25	43.25
Over-all length of engine in.	33.68	33.68	33.68	33.68
With auxiliary drive starter mounting, in.	....	36.34	36.34	36.34
Weight standard engine, lb.	475.0	497.7	492.5	494.7
Weight added for:				
Radio shielding and spark plugs, lb.	....		8.60	8.60
Fuel pump drive, lb.	....	0.70	0.70	0.70
Generator drive, lb.	....	1.83	1.83	1.83
Vacuum pump drive, lb.	....	0.89	0.89	0.89
Hydropropeller control, lb.	....	1.85	1.85	1.85
Auxiliary accessory mounting, lb.	....	2.40	2.40	2.40
Priming pump—Lunkenheimer, lb.	1.10	1.10	1.10	1.10
Constant-speed governor drive, lb.	......	......	......	......
Dual tachometer drive, lb.	2.45	2.45	2.45	2.45
Cowling assembly with carburetor air heater, lb.	6.11			
Exhaust collector ring and exhaust pipes, lb.	18.13			
Tool kit, lb.	9.30	9.30	9.30	9.30
Ignition System:				
Dual type magneto (with two distributors)—Scintilla	SC-A	SC-A2	SC-A2	SC-A2
Magneto rotation viewed from top of engine	Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise
Speed of rotation—multiples of crank-shaft speed	1⅛	1⅛	1⅛	1⅛
Breaker point gap, in.	0.012	0.012	0.012	0.012
Spark plugs:				
Gap, in.	0.015	0.015	0.015	0.015
Spark occurs, B.T.C.	30	30	30	
Fuel System:				
Carburetor, Bendix-Stromberg	NA-R7A	NA-R7A	NA-R7A	NA-R7A
Fuel required (AMCOR Spec. No. 201) min. octane No.	65	80	73	
Fuel pump—Romec (2.63 lb.)	C-6	C-6	C-6	C-6
—Pesco (2.10 lb.)	R-400-BC	R-400-BC	R-400-BC	R-400-BC
Generator—Eclipse (15.00 lb.)	G-2	G-2	G-2	G-2
—Eclipse (20.00 lb.)	AL-2	AL-2	AL-2	AL-2
Starter—Eclipse (18.50 lb.)	E-80	E-80	E-80	E-80
—Eclipse (24.50 lb.)	....	....	....	....
Vacuum pump—Pesco (3.35 lb.)	....	....	....	....
Governor—hydro constant-speed propeller (3.65 lb.)	....	....	....	....

engine is thus obtained in flight when the engine is enclosed in a ring cowling. Particular care is necessary, however, when operating these engines on the ground to insure that the *greatly* reduced air flow over the cylinder fins does not cause overheating with resultant damage to the engine.

Crankshaft.—The crankshaft is a two-piece, single-throw, counterbalanced assembly supported in the crankcase assembly by a main bearing on each side of the crankshaft throw. A thrust bearing in the front crankcase section takes the propeller thrust as well as the radial load. The front crankshaft section, which is bored through practically its entire length for lightness, incorporates the shaft proper, the front crank cheek with its integral counterweight, and the crankpin.

The rear crankshaft section consists of the rear crank cheek with its integral counterweight and the rear main bearing hub. The rear crank cheek is bored at one end to receive the crankpin and is bored for the crank-

of Lycoming Radial Engines

R-680-B6	R-680-D5	R-680-D6	R-680-E1	R-680-E2	R-680-E3	R-530-D1	R-530-D2
111	172	173	202	202	202	182	183
5.5 to 1	6.5 to 1	5.5 to 1	6.2 to 1	5.5 to 1	7.0 to 1	6.5 to 1	5.5 to 1
2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300
2,100	2,100	2,100	2,200	2,200	2,200	2,100	2,100
245	260	245	290	280	300	220	210
225	245	225	275	265	285	200	190
5.90	4.78	4.78	4.78	4.78	4.78	5.25	5.25
0.62	0.34	0.34	0.34	0.34	0.34	0.50	0.50
43.25	43.5	43.5	43.5	43.5	43.5	43.5	43.5
33.68	37.04	37.04	37.04	37.04	37.04	34.26	34.26
36.34							
492.5	505.0	505.0	514.0	514.0	514.0	430.0	430.0
8.60	7.59	7.63	7.20	7.20	7.20	6.25	6.35
0.70	1.42	1.42	1.40	1.40	1.40	1.62	1.62
1.83	1.31	1.31	1.39	1.39	1.39	1.61	1.61
0.89	0.77	0.77	0.77	0.77	0.77		
1.85	....	....	....	....	....	0.63	0.63
2.40							
1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
....	1.40	1.40	1.40	1.40	1.40		
2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
SC-A2	SC-A2	SC-A2	SC-A2	SC-A2	SC-A2	SC-A2	SC-A2
Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise	Counter-clockwise
1⅛	1⅛	1⅛	1⅛	1⅛	1⅛	⅞	⅞
0.012	Left 0.016	Left 0.016	Left 0.016	Left 0.016	Left 0.016	Left 0.016	Left 0.016
	Right 0.012	Right 0.012	Right 0.012	Right 0.012	Right 0.012	Right 0.012	Right 0.012
0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
30	Left 34	Left 34	Left 34	Left 34	Left 34	Left 34	Left 34
	Right 30	Right 30	Right 30	Right 30	Right 30	Right 30	Right 30
NA-R-7A	NA-R7A	NA-R7A	NA-R7A	NA-R7A	NA-R7A	NA-R7A	NA-R7A
73	80	73	80	73	87	80	73
C-6	C-6	C-6	....	....	....	C-6	C-6
R-400-BC	R-400-BC	R-400-BC	R-400-BC	R-400-BC	R-400-BC	R-400-BC	R-400-BC
G-2	G-1	G-1	G-1	G-1	G-1	G-2	G-2
AL-2	AL-1	AL-1	AL-1	AL-1	AL-1	AL-2	AL-2
E-80	E-80	E-80	....	....	....	E-80	E-80
....	....	....	F-141	F-141	F-141		
....	B-2A	B-2A	B-2A	B-2A	B-2A		
	mod. 194	mod. 194	mod. 194	mod. 194	mod. 194		
....	Hamilton-Standard	Hamilton-Standard	Hamilton-Standard	Hamilton-Standard	Hamilton-Standard		

shaft clamping bolt. The end of the crank cheek is split through the crankpin bore to permit proper clamping action on the crankpin when the clamping bolt and nut are tightened. The rear main bearing hub is bored for a splined bushing which drives the accessory drive shaft.

The front and rear counterweights are drilled for the use of an aligning bar when assembling the two sections of the crankshaft.

Master Rod and Link Rods.—A one-piece master rod and eight link rods are used. The master rod is machined from a chrome-nickel steel forging, the widened flanges on the large end being drilled to receive the link pins. The master rod is provided with a steel-backed lead-bronze bearing for the crankshaft and an aluminum-bronze bushing for the piston pin. *The master rod is assembled in cylinder 7 in all nine-cylinder engines and in cylinder 5 in the seven-cylinder engines* in order to ensure proper lubrication of the master rod piston when starting the engine and when

operating at idling speeds. The link rods are articulated to the master rod with nitralloy link pins. Forged aluminum alloy link rods are used in model R-680, R-680-B, and R-680-D Series engines. Forged molybdenum steel link rods with aluminum bronze piston-pin and link-pin bushings are used in model R-680-E and R-530-D Series Engines.

Pistons and Pins.—The pistons are aluminum alloy forgings. The 5.5 to 1 compression engine models have the standard flathead piston; the domed type piston is used in all other engine models. Three compression rings and one oil regulator ring are used above the piston pin, with one oil scraper ring below it.

The full-floating type piston pins are made of nitralloy, ground and polished to a high finish. Aluminum alloy plugs are inserted in each end of the pins.

Valves.—The valves have a modified tulip-shaped head and are machined from steel forgings. The intake valves are made of tungsten steel with solid stems and slightly concave heads. The exhaust valves are made of chrome tungsten steel with hollow stems containing metallic sodium as a cooling medium.

Valve Operating Mechanism.—The cam assembly, rotating on a steel sleeve around the front of the crankshaft, is driven by spur gears in the *opposite direction to the crankshaft rotation.* The cam is driven at *one-eighth* engine speed in the nine-cylinder models and *one-sixth* engine speed in the seven-cylinder models. The lobes on the cam assembly actuate the cam followers which operate the exhaust and intake valves through push rods and rocker arms.

The cam assembly is a hardened steel ring with two rows of lobes on the outside circumference and an integral spur gear on the inside. This ring is riveted to an aluminum alloy hub which supports the cam assembly on the crankshaft sleeve. A cam drive gear, keyed to the crankshaft, drives the large spur gear on a cam idler gear which is mounted on the front main bearing plate. The small gear on the cam idler gear is in mesh with the internal spur gear on the cam ring, thus rotating the cam assembly. On model R-680-D and R-680-E Series engines, when a constant-speed governor drive is installed, a spur gear is incorporated on the front of the cam spider, the gear being attached by means of nuts and bolts.

The push rods of seamless steel tubing, with hardened steel ball ends pressed into each end, are completely enclosed by removable, two-piece, oil-tight shroud tubes. The shroud tubes of engines equipped with automatic valve gear lubrication are of one-piece construction and are attached to the shroud tube flanges with rubber hose and clamps.

Each valve rocker arm is supported by two ball bearings mounted on a rocker arm bolt in each rocker box. A ball socket in the valve rocker adjusting screw receives one end of the push rod. Rollers rotating on sleeves riveted in the other end of the rocker arm minimize friction and wear on the end of the valve stem. Except on engine provided with automatic valve gear lubrication, a Zerk type pressure lubricator is provided in each rocker arm bolt for the purpose of lubricating the rocker arm, bearings, and push rod ball ends.

Three concentric springs are used on each exhaust valve and three springs on each intake valve, except on model R-680-D, R-680-E, and R-530-D Series engines which employ two heavier springs on each valve. The springs consist of varying-pitch coils of round wire, wound in the same direction in order to induce valve rotation. The springs are held in place by two

retaining washers. The inner washer seats on the valve guide and the outer washer is secured to the valve stem by a split conical-shaped valve key fitting into a groove on the valve stem. A steel circlip is used in a groove on each valve stem to prevent the possibility of the valve's dropping into the cylinder.

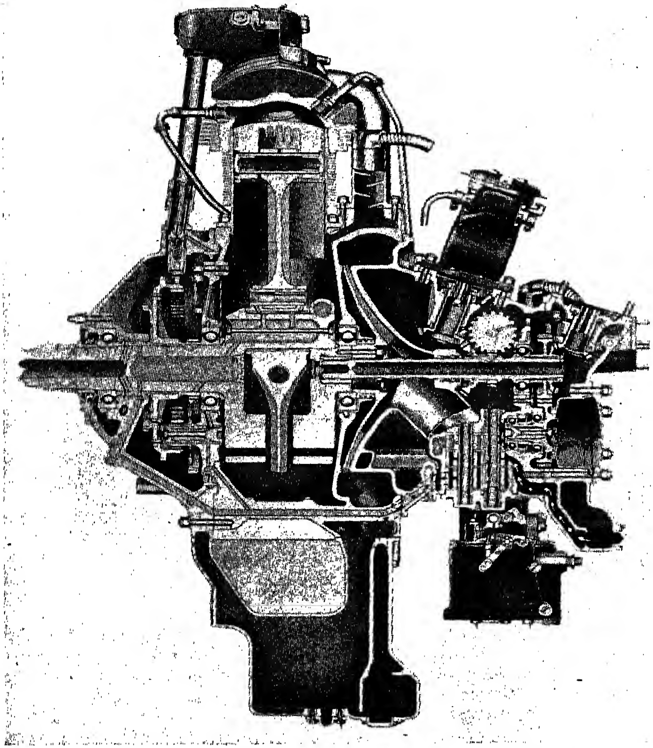


FIG. 17.—The oiling system of the Lycoming radial engine.

Oil Sump.—The oil sump of cast magnesium alloy is attached by studs and nuts to the main crankcase section and thrust bearing housing between cylinders 5 and 6 in nine-cylinder engines and between cylinders 4 and 5 in seven-cylinder engines.

Oil from the thrust bearing housing and main crankcase section drains into this sump. This oil is scavenged through the removable oil strainer screen in the sump by one of the two scavenging oil pumps. A larger oil sump is used on engines provided with automatic valve gear lubrication.

Ignition System.—Ignition is furnished by one Scintilla, dual type vertical magneto mounted on top of the accessory drive housing, with two independent distributors, mounted one on each side of the same housing. Magneto details will be found under Scintilla magneto in a later section.

An individual radio-shielded ignition harness is available as standard equipment on all current engine models.

Lubrication System.—Figure 17 shows the lubrication system is of the full-pressure type except for the cylinder walls and piston pins which are lubricated by excess oil thrown from the crankpin. The engine oil pump consists of one pressure pump and two scavenging pumps built into one complete unit and mounted in the lower left side of the accessory drive housing.

Oil is drawn from the supply line by the pressure pump and is forced through drilled passages into the forward end of the crankshaft, into the cam idler gear pin, into the distributor shaft, and, on engines equipped with automatic valve gear lubrication, into the cam followers, through the push rods to the valve rocker bearings.

On model R-680-D and R-680-E Series engines, the thrust bearing housing and the front crankshaft are drilled to provide the necessary oil passages for hydraulically operated controllable propellers with either a manual control or a constant-speed governor control. On these engines the front crankshaft oil seal plug must be removed when hydraulic type controllable propellers are to be used. The pressure oil in the distributor shaft lubricates the distributor shaft bearings through holes drilled in the shaft. The tachometer drive and the vacuum pump drive in the model R-680-D and R-680-E Series engines are also lubricated by pressure oil. All other gears and bearings in the accessory housing are lubricated by splash from the distributor shaft bearings.

Oil pressure is controlled by the oil pressure relief valve, mounted on the left side of the accessory drive housing. The pressure relief valve unit consists of a ball and spring relief valve which lifts from its seat when the desired oil pressure is obtained and discharges the excess oil back to the inlet side of the pressure pump. The recommended oil pressure (50–75 lb. per sq. in.) may be obtained by turning the adjusting screw so as to increase or decrease the tension on the oil relief spring.

Both scavenging pumps discharge the hot oil into an oil jacket around the carburetor riser in the accessory drive housing.

On model R-680-D and R-680-E Series engines a Cuno oil filter is built into the starter drive housing which is attached to the rear of the accessory drive housing. Oil is led directly to the oil filter from the oil pressure pump and from the filter to the oil pressure relief valve assembly. On these engines, the oil relief valve incorporates a second ball and spring check valve to prevent oil leakage through the oil pump to the engine when the engine is not operating.

Propellers.—The crankshaft is splined for the installation of a No. 20 S.A.E. spline propeller hub. Provisions for the installation of the Lycoming controllable propeller as well as the control mechanism for a hydraulic type controllable propeller is incorporated in current engine models. Model R-680-D and R-680-E Series engines provide for the installation of a constant-speed governor drive, as well as the standard manual control level for the hydraulic type controllable propeller.

Accessories and Equipment.—Model R-680, R-680-B, and R-530-D Series engines are equipped with a carburetor, fuel priming connections, a

dual type magneto, propeller hub attaching parts, tachometer drive connection, and an operator's manual. In addition to the above, the following optional equipment is available: pressure type cylinder cooling baffles, individual radio shielding, dual tachometer drive connections, provision for hydropropeller control, mounting flanges and drives for a generator, fuel pump or auxiliary fuel pump, and auxiliary vacuum pump.

ENGINE TROUBLES AND SERVICE ADJUSTMENTS

Routine inspection after 25 and 100 hr flying time is much the same as in the other models. Generally speaking all aircraft engine troubles involve similar causes. Basically the difference between opposed-cylinder engines and radial engines has little to do with starting or unsatisfactory operation. A symptom of engine trouble may usually be attributed to a number of possible sources, thus complicating its determination. Experience has proved that the best method of "trouble shooting" is (1) to decide on the various possible causes of a given trouble and (2), to eliminate the possible causes, one by one, beginning with the most probable.

The use of the following outline of common engine troubles and their possible causes is recommended to assist personnel in maintaining Lycoming aviation engines in serviceable condition with the least amount of wasted time.

Failure of Engine to Start.—This trouble may be due to any of the following listed causes:

1. *Improper Starting Procedure.*
2. *Lack of Fuel.*—Examine the fuel tanks, fuel line connections, shut-off cocks, and strainers.
3. *Overpriming or Insufficient Priming.*
4. *Incorrect Throttle Opening.*—The throttle should be approximately one-tenth open until the engine begins to fire.
5. *Defective Booster Coil.*—Check the wiring and operation of the booster coil.
6. *Ignition Wiring.*—Examine the wiring for wear, fractures, or incorrect connections.
7. *Spark Plugs.*—Remove the spark plugs, inspect them for cleanliness, and check the gaps for 0.015 in. clearance.
8. *Improper Opening or Closing of Valve.*—Check for proper valve tappet clearance of 0.015 in. or, if the valve is sticking, apply penetrating oil to the valve stem and turn the engine over by hand until the valve operates freely.
9. *Water in Carburetor.*—Remove the drain plug and permit the water to drain off.
10. *Magneto Breaker Points.*—Check the points for 0.012 in. clearance and for cleanliness.
11. *Cold Oil.*—With the ignition switch "off," turn the engine over by hand. If the engine is stiff, the oil should be drained and preheated before attempting to start the engine.
12. *Timing.*—Check the magneto timing as described below.

Uneven Running and Low Power.—If the engine speed drops excessively or if the engine runs unevenly, the trouble may usually be traced to any of the following listed causes:

1. *Rich or Lean Mixture.*—Uneven running and black smoke from the exhaust are evidence of too rich a mixture. Too lean a mixture is usually indicated by uneven running, overheating, and backfiring. Inspect the carburetor for leaks and check the jets for tightness.
2. *Leakage in Induction System.*—Inspect the intake pipes for cracks and for leakage at the joints. Check the carburetor and intake manifold flanges for tightness.
3. *Spark Plugs.*—Inspect the spark plugs for cleanliness and for proper gap clearance of 0.015 in.
4. *Ignition Harness.*—Check the ignition harness for broken or burned cables, poor connections, and damaged insulation.
5. *Valve Gear.*—Check the valve tappet clearance. Inspect the valve springs for fractures. Check the valves for sticking and for carbon deposits on the valve or valve seat.
6. *Magneto.*—Check the magneto breaker points for pitting and for proper clearance of 0.012 in.

7. *Fuel.*—See that the proper fuel is being used and that it is free from water or foreign matter.
8. *Carburetor Air Heater Operation.*—See that this control is being used properly.

Rough running of the engine after initial installation in the airplane may also be due to

1. *Propeller.*—Check the propeller by installing a similar type of propeller which is known to run smoothly on another engine. Also, check the propeller for balance and track.
2. *Propeller Hub Rear Cone.*—Check the cone for galling and concentricity of cone surfaces with inside diameter.
3. *Engine Mount.*—Check the engine mount for cracked or broken members and check the eng'ne mouting bolts for tightness. Check the rubber bushings on the mount for general condition.

Excessive Oil Temperature.—An excessive rise in oil temperature may result from

1. *Insufficient Supply of Lubricating Oil.*—At least 2 gal. are required.
2. *Inferior Grade of Lubricating Oil.*
3. *Foreign Matter or Carbon Particles in Lubricating Oil.*—Remove the oil strainer, inspect, clean, and replace.
4. *Scavenger Oil Pumps.*—Not draining the crankcase properly.
5. *Excessive Clearance of Master Rod Rearing.*—Causing excessive heat.

Low Oil Pressure.—Low oil pressure or lack of oil pressure may result from

1. *Leak in Oil Lines.*—Check the oil supply lines and connections for leakage. Check the oil thermometer and oil pressure gage connections for tightness.
2. *Dirt in Oil Screens.*
3. *Foam in Oil Tank.*—The return oil line from the engine should enter the oil tank so as to produce as little splashing as possible and to permit the air, trapped in the return line, to separate readily from the oil.
4. *Worn Bearings.*—An excessively worn bearing surface may reduce the oil pressure in the lubricating system and require overhaul of the engine.
5. *Oil Pressure Relief Valve.*—Before adjusting the oil pressure relief valve to correct low oil pressure, a thorough investigation should first be made of all other possible causes already listed.

The following are miscellaneous adjustments, pertaining to service maintenance and inspection between overhaul periods:

Carburetor Idling Adjustment.—After a newly installed engine is warmed up, check the idling adjustment of the carburetor as follows:

1. If a controllable propeller is used, see that the blades are in the minimum blade angle setting.
2. Regulate the mixture for idling by adjusting the small lever on the rear side of the carburetor barrel with the throttle fully closed. Proper mixture strength is obtained by moving the lever toward "lean" (left side of the engine) until the engine loses speed, and then moving the lever two notches toward "rich" (right side of the engine).
3. Adjust the engine idling speed by turning the set screw in the throttle lever to obtain an engine speed of 400 r.p.m. when the throttle is fully closed.

Oil Pressure Relief Valve Adjustment.—Prior to adjusting the oil pressure relief valve in order to correct for excessive or low oil pressure in service, a thorough investigation should first be made of all other possible causes as already outlined.

The oil relief valve is located on the left side of the engine accessory drive housing. Loosen the relief valve lock nut and turn the adjusting screw *in* to increase the engine oil pressure, and *out* to decrease the oil pressure.

Magneto and Distributor Timing.—The magneto must be timed so that the breaker points are just beginning to open when the engine crankshaft is 30 deg. before top dead center of cylinder 1 on the compression stroke. On these engines the magneto breaker points open at 34 deg. for the left and 30 deg. for the right breaker points.

The distributors used with the magneto are mounted on the left and right sides of the engine accessory housing. Each distributor cap and an insulating disk are attached to the housing with three fillister head screws. The distributor rotors are attached to each end of the distributor drive shaft with couplings. To time the distributors properly follow these instructions:

Timing Magneto.—With the magneto removed and the magneto drive assembly firmly in place, rotate the crankshaft in the direction of engine rotation until it is 30 deg. before top dead center cylinder 1 on the compression stroke. Rotate the magneto shaft so that the magneto breaker points are just beginning to open. At this time also see that the breaker points are clean and free from pitting. Set the breaker clearance at 0.012 in. for *both breaker points* of model R-680 and R-680-B Series engines and for the *right breaker points* of model R-680-D, R-680-E, and R-530 Series engines. Set the left breaker points on these latter engines at 0.016 in. A minimum allowable clearance of 0.010 in. for the right breaker points and a maximum of 0.018 in. for the left may be used if necessary to obtain the desired 4-deg. staggered spark on these engines.

Assemble the magneto on the magneto mounting so that the magneto shaft enters the splines in the drive shaft and the magneto mounting studs enter the slots in the magneto mounting flange. With breaker lever in "full advance spark" position, slowly rotate the magneto asembly with respect to the mounting studs and in the direction of the magneto rotation (indicated by the arrow stamped on the magneto) until the magneto breaker points are just beginning to open. (A convenient method of checking the point of opening is to insert a piece of cellophane tissue between the contact points and pull on the tissue lightly. The points are just opening when the tissue slips from the points while the magneto assembly is being rotated on its mounting.) Care must be exercised to prevent movement of the crankshaft during this operation.

Lock the magneto in this position with washers, nuts, and lock nuts. Check the magneto setting by first rotating the crankshaft backward until the magneto breaker points are fully closed and then rotating the crankshaft slowly in the direction of engine rotation until the magneto breaker points are just beginning to open. The magneto is properly timed when the breaker points are just beginning to open and the crankshaft is 30 deg. before top dead center of cylinder 1 on the compression stroke on model R-680 and R-680-B Series engines. On model R-680-D, R-680-E, and R-530 Series engines the crankshaft is at 34 deg. when the left breaker points open and 30 deg. when the right breaker points open. Assemble the ignition cable from each distributor to the corresponding side of the magneto, in accordance with the wiring diagram in Fig. 13.

Timing Distributors.—Rotate the crankshaft to the firing position for cylinder 1, or 30 deg. before top dead center on the compression stroke, as for magneto timing. Assemble a distributor insulating disk over the dowels on each distributor mounting so that the arrow stamped on each disk points in the direction of rotation of the distributor shaft, that is, clockwise when facing the right distributor and counterclockwise when facing the

left distributor. Temporarily place each distributor contact finger over the dowels on the distributor couplings. Assemble these parts over serrations on each end of the distributor shaft so that the arrow stamped on the finger points in the direction of the shaft's rotation and the contact segment aligns with the center of the square marked on the insulating plate.

Remove the contact fingers, leaving the couplings in position on the shaft. Attach each coupling securely to the end of the shaft with washer, nut, and cotter pin. Reassemble the contact fingers over the dowels on the couplings and attach securely with fillister head screws, locking screws together with lock wire. Assemble right-hand and left-hand distributor caps on the mounting over the dowels, being careful to see that the contact brushes are in place and operate freely on their springs. Attach each distributor cap securely with three fillister head screws and lock screws together with lock wire.

Removal and Assembly of Cylinder and Piston.—These instructions presume that the following disassembly, inspection, and reassembly will be performed by qualified personnel who are experienced in aviation engine overhaul practice.

First remove the exhaust collector attached to the cylinder. Remove the intercylinder baffles on each side of the cylinder to be removed. (It is not necessary to remove the cylinder head baffle if the same cylinder is to be reinstalled.) Remove the two rocker box covers. Remove the valve adjusting screws, push rods, and shroud tubes. Remove the intake pipe by completely unscrewing the packing nut that secures the intake pipe to the crankcase and then removing the nuts from the studs attaching the intake pipe flange to the cylinder head. Disconnect the ignition cables from the spark plugs and remove the spark plugs.

Move the piston to the top of its stroke in the cylinder, remove the cylinder hold-down nuts, and slide the cylinder off from the piston by a straight pull. Care must be exercised to prevent piston-pin plugs from falling out of the piston pin and to prevent damage to the cylinder skirt or the link rod. Remove the piston pin and the piston from the connecting rod. If the piston pin does not slide easily from the piston, support the piston and drive out the pin with a fiber drift or apply a small amount of heat directly to the piston head and tap the pin lightly.

The master connecting rod is placed in cylinder 7 in nine-cylinder engines and cylinder 5 in seven-cylinder engines. Therefore, in nine-cylinder engines, when several cylinders are removed, it is necessary to remove cylinder 7 last and install it first; in seven-cylinder engines, cylinder 5 is removed last and installed first in order to hold the connecting rods in their proper position. If the master cylinder is the only cylinder to be removed, particular care must be taken to see that the crankshaft is not removed while the cylinder is removed, otherwise, the scraper rings on the other pistons will come out of the cylinders and seriously damage the pistons and the skirts of these cylinders.

Remove the rocker arms from the cylinders by removing the cotter pin, nut, and washer from the rocker arm bolt and, with a small brass drift, driving the bolt from the rocker arm supports. If a bolt is unusually tight, support the cylinder head to avoid damaging the casting. Support the valves on the inside of the cylinder, depress the valve springs, and remove the valve keys, springs, washers, and circlips. The valve may now be removed from the inside of the cylinder.

Remove the piston rings from the piston, being careful not to damage the sides of the piston. Remove all carbon from the top of the piston, ring lands, and ring grooves, being careful not to scratch the piston. Carefully polish the metal from which the carbon was removed. *Do not polish or dress off the glaze on the piston skirt;* otherwise, several hours' run-in of the engine will be required to replace this glaze. However, if there are scores on the piston skirt which are not glazed over, and the piston is still serviceable, these scores should be worked down smooth with a fine stone and crocus cloth. If this is done, additional running-in of the engine is necessary.

Reassemble the piston rings on the piston, checking the side and gap clearance of the rings.

Assemble the valves in the cylinder, supporting the valves from the inside of the cylinder while the circlip, washers, springs, and valve keys are being installed. Reassemble the rocker arms on the cylinder.

Apply a generous coating of engine oil on the piston, rings, piston pin, and cylinder wall. Place a new paper gasket on the crankcase cylinder pad. Assemble the piston and pin on the connecting rod. Assemble the cylinder over the piston, using a piston ring clamp to avoid damage to the piston rings. Attach the cylinder securely to the crankcase, turning the nuts evenly and using hand pressure on a wrench handle no longer than 6 in. Lock with lock nuts. Reassemble the intake pipe with gasket shroud tubes and push rods. Adjust the valve tappet clearances to 0.015 in.

If new piston rings or pistons have been installed, the intercylinder baffles as well as the ring cowl must be removed during the engine run-in.

WHEN AN ENGINE MUST BE STORED

In order to neutralize the effect of the combustion of fuels containing tetraethyl lead in cylinders and on valves, engines should be treated with anticorrosion compound prior to each storage period. New engines are treated with anticorrosion compound before shipment from the factory.

Engines that have been treated with anticorrosion compound are to be prepared for service in the following manner.

The anticorrosion compound recommended for use in Lycoming Aircraft engines is known as "E.G.-174," manufactured by The Park Chemical Company, Detroit, Mich. Spraying apparatus, for applying this compound in the proper manner, is designated: Type C.L.F. Spray Gun with ⅜-in. diam. fluid hose, connections, and extension nozzle, as manufactured by the DeVilbiss Company, Toledo, Ohio.

Preparation for Storage.—Following operation on leaded gasoline, engines are to be prepared for storage by treatment with anticorrosion compound at the following periods:

1. *Upon Removal from Airplane.*—Engines that are removed from airplanes should be treated within two days unless it is known in advance that the engines will be disassembled for overhaul within one week from the time of removal.

2. *Following Overhaul Test.*—Engines should be treated upon completion of overhaul testing unless they are to be installed in airplanes within two days.

3. *Engines in Storage.*—All engines placed in storage, including engines installed in airplanes that will not be operated for a period of more than one week, should be treated within two days.

4. *Periodic Treatment of Engines in Storage.*—Each engine in storage should be retreated at the end of each six months.

If for any reason an engine in storage status is not treated as prescribed, it is necessary that it be given an inspection overhaul of cylinders and valve mechanism. The removal and assembly of cylinders are described on page 206. Following the inspection overhaul, the engine should be treated with anticorrosion compound unless it is known that the engine will again be operated within two days.

Method of Treatment.—Engines that are to be prepared for storage, as defined above, should be treated in accordance with the following procedure:

1. By placing them in a heated hangar or otherwise, allow the engine to heat up to at least 60°F.
2. Drain the oil from the engine.
3. Remove the front spark plug or shipping plug from each cylinder. Rotate the crankshaft so that each piston in turn is brought to the bottom of the suction stroke and each intake valve is fully opened. With the piston in this position insert spray gun nozzle through each front spark-plug hole and *completely* coat the cylinder wall, piston, head, and valves with a film of anticorrosion compound. Although excessive amounts of compound in the cylinders are unnecessary, it is essential that a film of the compound completely covers these surfaces in order to prevent corrosion.
4. In the same manner, spray a small quantity of anticorrosion compound into each exhaust port with the exhaust valve in the fully opened position. If the engine has exhaust collector rings installed, the exhaust valves may also be sprayed through the spark-plug holes provided that each exhaust valve is in the fully opened position when sprayed.
5. Apply a thin coating of petrolatum on all external, unpainted steel parts, using either a brush or spray.
6. After the foregoing treatment, wipe off all petrolatum, oil, and anticorrosion compound from the exposed rubber and painted parts.
7. Close all fuel and oil line connection openings, cover the cylinder ports, and replace the spark plugs or shipping plugs in the front spark-plug holes.

Preparation of Engines for Service after Treatment.—Engines that have been treated with anticorrosion compound, as just described, require that the following precautions be observed before placing the engines in service:

1. The petrolatum should be wiped from the external steel parts.
2. Remove the spark plugs or shipping plugs from the front spark-plug holes and rotate the crankshaft several revolutions.
3. While rotating the crankshaft, observe the valve mechanism for proper operation and see that excessive amounts of anticorrosion compound are not present in the cylinders.

Any excess compound should be removed through the spark-plug holes by draining or by means of a hand pump. Any evidence of sticking valves should be eliminated by lubricating the valve stems with penetrating oil and rotating the crankshaft by hand.

SECTION VI

MENASCO PIRATE ENGINES

MENASCO INVERTED-LINE ENGINES

Menasco air-cooled aircraft engines are made in 4-, 6-, and 12-cylinder models by the Menasco Mfg. Co. of Los Angeles, Calif. The four-cylinder engine is $4\frac{3}{4} \times 5\frac{1}{8}$ in. with a displacement of 363 cu. in. Compression

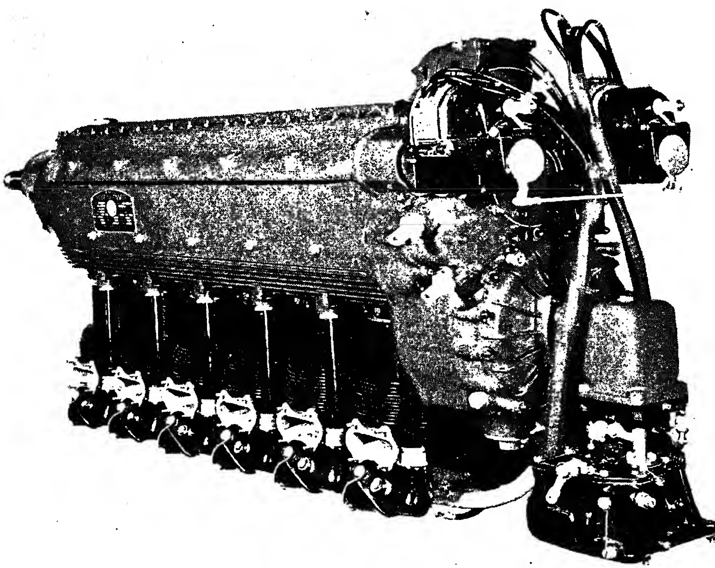


FIG. 1.—Menasco Super-Buccaneer: an inverted six, air-cooled engine.

ratio is 5.5 to 1. It has force-feed lubrication with a dry sump. It weighs 288 lb. without starter, fuel pump, hub, or air scoop. The scoop weighs about 4 lb.

The rated horsepower is 125 at 2,175 r.p.m. Fuel consumption is given as $\frac{1}{2}$ lb. per hour at 2,175 r.p.m.; oil consumption is 0.010 lb. at the same speed.

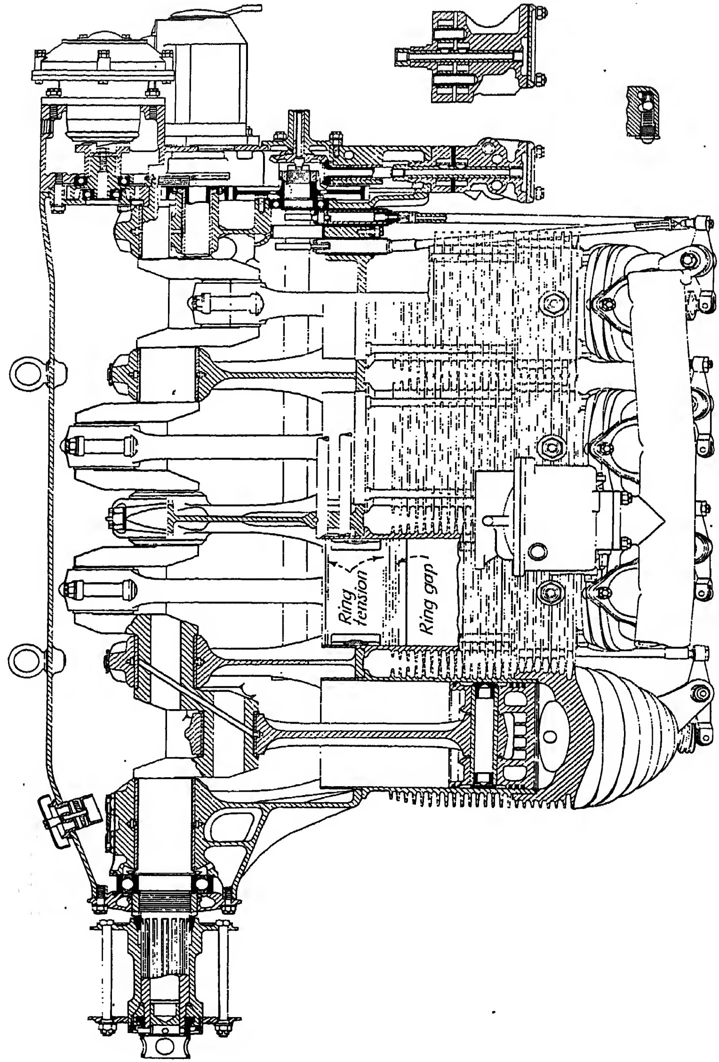


FIG. 2.—Section of Menasco four-cylinder Pirate engine.

A single-bank six-cylinder engine is seen in Fig. 1 and is known as the Super-Buccaneer. The four-cylinder Pirate is shown in section in Fig. 2, while Fig. 3 shows a Vega-Unitwin with 12 cylinders. This is a double engine with both crankshafts geared together with a sort of free-wheeling

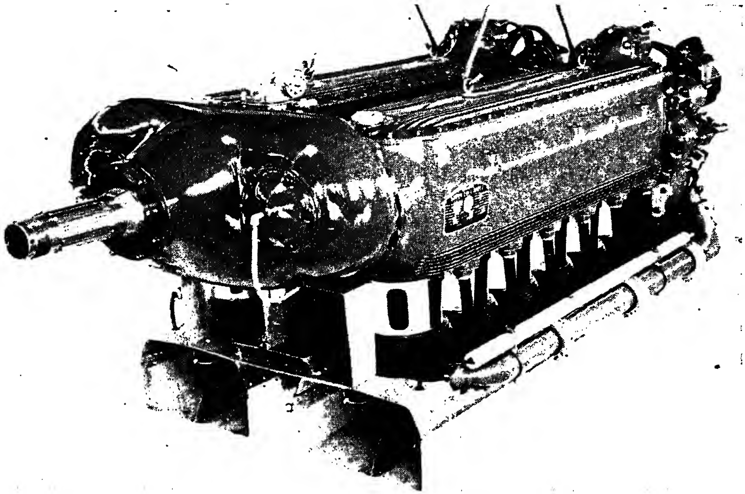


FIG. 3.—Menasco 12-cylinder Vega-Unitwin engine.

device. An enlarged vertical section of the cylinder construction is seen in Fig. 4. Detailed specifications of the Pirate engine are given in Table 1.

THE PIRATE ENGINE

The Menasco C4 is a four-cylinder, inverted, in-line, air-cooled engine. The inverted engine provides a low center of gravity and a high center of thrust. The exhaust manifold is simplified by the lowness of the ports which permits the gas to be discharged downward. The engine is equipped with a starter mounting flange and a fuel pump drive. In some installations, however, a fuel pump may not be necessary because of the low position of the carburetor on the inverted engine. The engine may also be equipped with a generator. The engine can be installed either as a tractor or pusher without any alterations; it has detachable finned heads, the fore and aft locations of the rocker arms pivoted on ball bearings. The crankshaft has simple oil circuits, and the grouping of all accessories at the rear.

In descriptions the following definitions will be used: the propeller end of the engine will be called the "front" and the accessory end the "rear." The direction of rotation of the crankshaft is counterclockwise when viewed from the propeller. The cylinders are numbered consecutively from the propeller end, the cylinder adjacent to the propeller being No. 1. The right and left sides of the engine will be referred to as viewed from the rear or accessory end.

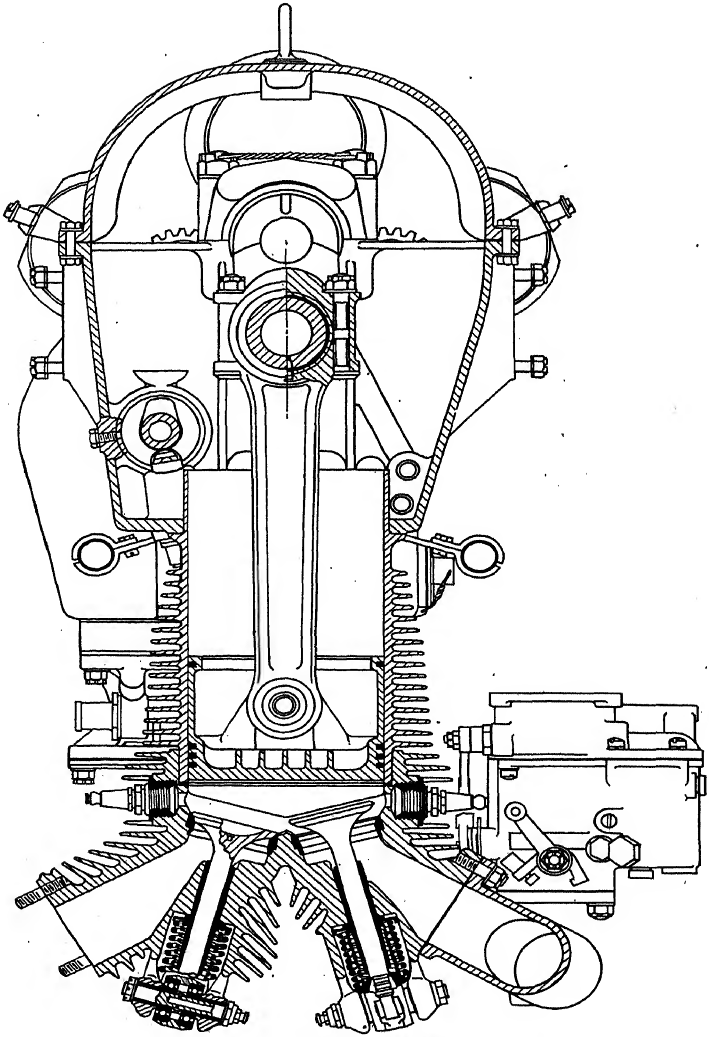


FIG. 4.—Vertical section of Menasco cylinders.

Crankcase and Crankshaft.—The crankcase is split on the crankshaft center line. The lower case houses the crankshaft and camshaft and supports the cylinder assemblies. The upper case is provided with a breather and two screw eyes for use in lifting the engine. The crankcase is of heat-treated aluminum alloy and of very sturdy design, with four webbed partitions extending to the bottom of the crankcase supporting the four interchangeable main bearings. The five main bearings are bronze backed, babbitt lined. The shells are of cylindrical shape, and there are no flanges at the end for location and thrust. Both halves are located by dowels. This allows the propeller thrust bearing to locate the crankshaft in the case.

The crankshaft is of nickel-chromium steel, heat-treated and machined all over. The propeller end of the shaft is splined to No. 10 S.A.E.

Table 1.—Pirate Specifications

Rating:	
Rated power, hp	125
Rated speed, r.p.m.	2,175
Bore, in.	4.75
Stroke, in.	5.125
Piston displacement, cu. in.	363
Compression ratio	5.5 to 1
Propeller:	
Speed	Crankshaft
Rotation (looking at propeller end of engine)	Counterclockwise
Thrust	Tractor or pusher installation
Tachometer:	
Speed	½ crankshaft
Rotation (looking at tachometer drive end on engine)	Clockwise
Overall Dimensions:	
Length:	
From spark control to end of propeller nut (Scintilla magnetos), in.	47 13/16
From spark control to wood propeller center line (Scintilla magnetos), in.	43 15/16
Height:	
From crankshaft centerline to eyebolts, in.	6 7/16
From crankshaft center line to rockers, in.	21 ¾
Total height, in.	28 9/16
Width:	
Between engine mount pads, in.	11 ⅛
Maximum width at magnetos, in.	14 ⅝
Ignition:	
Rotation	clockwise, both (looking at end of magneto shaft)
Speed	Crankshaft
Timing (full advanced)	Intake—30° B.T.C. Exhaust—35° B.T.C.
Firing order	1-3-4-2
Spark Plugs:	
Make	B.G.
Model	4B2
Gap, in.	0.015 to 0.018
Valve Timing (Cold)	
Inlet opens	17 deg. B.T.C.
Inlet closes	77 deg. A.B.C.
Exhaust opens	67 deg. B.B.C.
Exhaust closes	27 deg. A.T.C.
Valve tappet clearance cold, intake and exhaust (measured at valve stem end), in.	0.007
Fuel System:	
Carburetor type	Stromberg NA-R4D
Carburetor type	Stromberg Na-R4D
Carburetor setting:	
Venturi (choke), in.	1 7/16
Main metering jet	No. 43
Main air bleed	No. 69
Accelerating pump metering jet	No. 65
Idle metering jet	No. 70
Idle air bleed	No. 45
Float level below parting line, in.	9/16
Fuel consumption:	
Cruising 75% throttle at 1,950 r.p.m.	
46 lb. or 7¾ gal. per hr.	
Full throttle at 2,175 r.p.m.	
62½ lb. or 10½ gal. per hr.	

Table 1.—Pirate Specifications (*Continued*)

Lubricating System:	
Oil consumption (approximately): 0.010 lb. per b.hp.-hr. or 1.4 pt. per hr. at rated hp.	
Correct oil pressure (at rated speed and recommended oil temperature): 40 to 50 lb. per sq. in.	
Oil temperature in sump:	
Maximum permissible	200°F.
Recommended	160°F.
Standard Equipment and Weight:	
Weight of C4, with propeller nut and cones	293 lb.
The following accessories are shipped with each engine (weights not included in the above):	
Air scoop, lb	4
4 engine supports, lb	2½
4 exhaust flanges, lb	1
Tool kit, lb	4½
Handbook, lb	½
Additional Equipment and Weight:	
The following accessories can be supplied:	
Fuel pump { Evans model 9026, lb	2½
Fuel pump { or Pesco type F4-RB1, lb	2¼
Hand cranking gear, Eclipse, type 4H4, model M 2234 (including crank), lb	12½
Direct electric starter:	
Eclipse, type Y-150, lb	16¼
or Eclipse, type E-80, lb	18
Menasco starter drive assembly, lb	2
Hub assembly for wooden propeller, lb	7
Propeller hub for metal blades, lb	10½
Electric generator, lb	16
Generator adaptor, lb	2
Shipping Data:	
Over-all size of crate, in	24⅝ × 37 × 56⅞ (or 30 cu. ft.)
Weight, crated, lb	475

Connecting Rods and Pins.—The connecting rods are forged duralumin of I-beam section column with ample fillets. The crankpin bearing is bronzed back babbitt lined and is located in the rod with a dowel. The

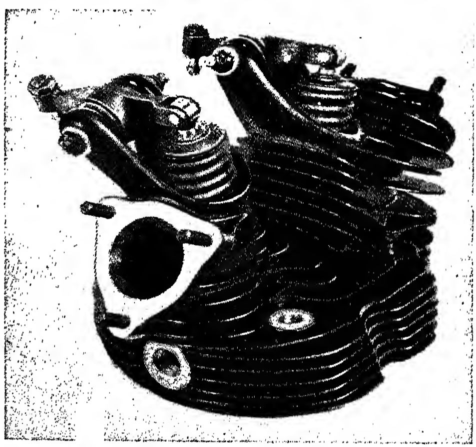


Fig. 5.—Cylinder head is easily removed.

piston pins float directly in the rod and in the piston. Duralumin buttons are pressed into the ends of the pins to prevent scoring the cylinder walls.

Pistons.—The pistons are the full skirt type relieved at the sides, machined from heat-treated aluminum alloy, permanent molded castings. There are

three compression rings above the pin and one oil scraper ring at the bottom of the skirt.

Cylinder Head and Cylinder.—The cylinders are of nickel iron and have thin fins of fine pitch and great length. The sleeves extend well into the crankcase. The cylinder heads are cast of aluminum alloy. The combustion chamber has a convex dome. Valves have a 15-deg. angle and the spark plugs are located at a 90-deg. angle. Brackets for supporting the rocker arms are integral parts of the casting.

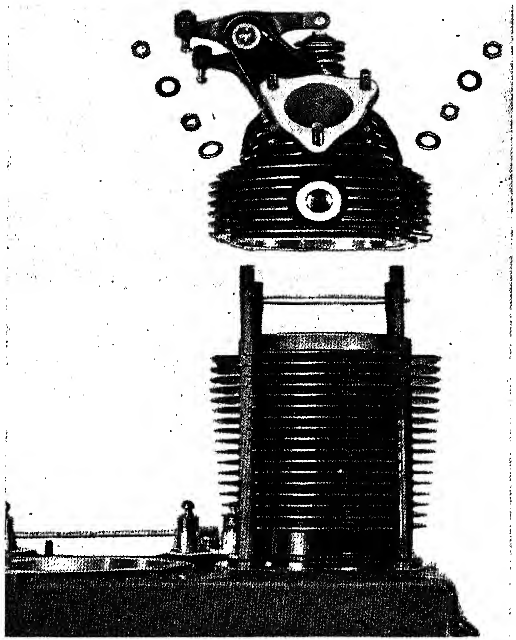


FIG. 6.—Cylinder assembly. Note gasket suspended between head and cylinder.

The intake and exhaust ports are symmetrical and are inclined from the vertical to permit the use of long cooling fins and allow the rocker arms to be located in a fore and aft position, enabling easy air flow between the ports.

The valve seats are made from special bronze, shrunk and rolled in. Spark-plug bushings are made from bronze, shrunk, screwed, and pinned in. The cylinder-head gasket is of solid, soft anneal copper, with circular serrations on the contact surfaces.

The cylinder head and cylinder are secured to the crankcase by four nickel steel studs. Cylinder heads are detachable and may easily be removed from the cylinders for access to valves for grinding (see Fig. 5).

Figures 6 and 7 show details of how the cylinders come apart and details of the different parts.

Camshaft.—The camshaft is a nickel-chromium forging with the wearing surfaces casehardened. It runs in four bronze bearings and one narrow-width deep-groove ball bearing.

Valve Mechanism.—The valve mechanism is simple, direct, and light, employing rollers at both tappet and rocker arm points of contact, and ball ends to engage with the push rod. Tubular duralumin push rods

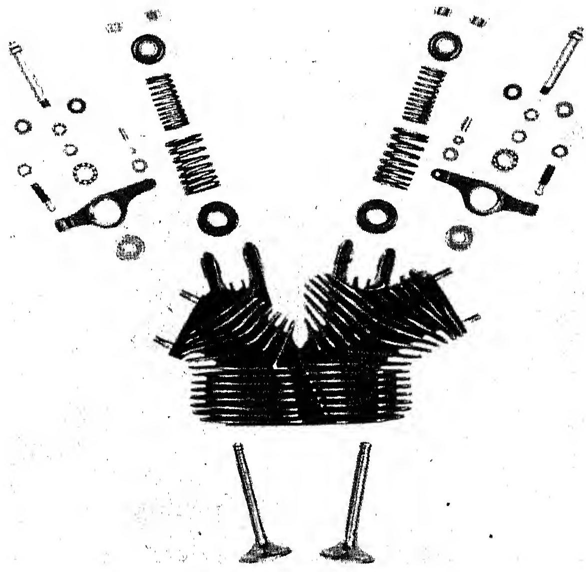


Fig. 7.—Parts used in cylinder-head assembly.

with hardened steel cup ends operate the rocker arms. The tappet guides are duralumin forgings. The angularity of the push rods is not severe, and there is practically none on the exhaust rod where the greatest load is developed as a result of opening the valve against the combustion pressure.

Tappet adjustment is provided for at the ball end of the rocker arm and, when the engine is installed in a plane, is very accessible from the ground. The ball end is threaded into the rocker arm and locked by a nut.

The rocker arms are of nickel-chromium steel and are interchangeable. Each rocker is mounted on two ball bearings of the oil seal type.

The intake and exhaust valves are of the tulip type. Two concentric valve springs are used and are secured to the valve stem by a split cone and washer.

The intake and exhaust valve assemblies are not interchangeable. The material differs and the intake valve stem is smaller than the exhaust valve stem. The split cones are different also.

The valve timing is built into the engine and requires no adjustment. The teeth of the gears in the camshaft train are marked to ensure proper assembly (see Fig. 15).

Accessories.—The magneto and camshaft gear train consists of only four stub tooth gears. The two magneto gears, one of which drives the camshaft gear, are identical and bear directly in the crankcase. The magnetos are driven through micarta Oldham's couplings, an impulse starter interconnecting one magneto.

A starter mounting flange S.A.E. 5 in. diam. with a 4-in. bolt circle is provided at the top of the accessory case between the magnetos.

Either the 4 to 1 ratio hand cranking gear or the direct cranking electric starter may be used. The starter engages with a gear supported on ball bearings housed in the accessory case and is driven at crankshaft speed.

A generator mounting flange is provided for installing a generator on the engine.

The oil pump is located at the bottom of the accessory case below the level of the rear oil sump. A vertical shaft driving the oil and fuel pumps runs in a bronze bushing in the accessory case and is driven through bevel gears. One of these is driven by the camshaft through a tongue drive. The shaft of the bevel gear, which engages with the camshaft, is slotted for tachometer connection.

The oil pump is of the gear type and consists of one pressure and two scavenging pumps. The conventional pressure lubrication with dry sump is used.

Lubrication.—Oil is taken from the tank by the pressure pump and filtered through a strainer. Part of the oil is by-passed directly into the line going back to the tank, maintaining a constant pressure on the oil line in the engine. The oil strainer is spring loaded and will allow the oil to by-pass if the screen becomes clogged.

Filtered oil is delivered to the five main crankshaft bearings through a duralumin tube pressed into the case and connected by drilled holes from the bearings. The oil enters the crankshaft at four of the five main bearings, each of the four feeding a connecting rod bearing.

The piston pins, pistons, camshaft, tappets, and accessory gear train are lubricated by splash. The ball ends of the rocker arms are oiled by gravity feed through the tubular push rods. An Alemite nipple is provided on each rocker arm bolt to reach the rocker arm ball bearings.

The crankcase is scavenged by two independent scavenging pumps, each of ample capacity. Oil collected in the front portion of the crankcase sump is scavenged through a duralumin tube in the case below the pressure line.

Oil is picked up only at the front end of the tube, through drilled holes Oil drained into the accessory case sump is scavenged through a short drilled hole connecting with the pump. Large oil drain holes are provided in each crankcase partition, so that oil may flow freely from one sump to the other when the engine is inclined.

It is not possible for both pumps to air-lock at the same time, as one pump is always primed regardless of the position of the engine.

Manifolding and Carburetion.—An NA-R4D Stromberg downdraft carburetor is located upon, and feeds into, the center of the one-piece aluminum

intake manifold. The carburetor has an accelerating pump and manually operated altitude control.

An S.A.E. fuel pump drive is provided on the bottom of the oil pump although in some installations a fuel pump may not be necessary, as the carburetor is located very low on the inverted engine, enabling gravity feed to be used.

Ignition.—Ignition is furnished by two four-cylinder, flange-type magnetos mounted on the accessory case, each of which fires a bank of four spark plugs. Wires are housed in aluminum conduits on each side of the crankcase; those at the magneto ends are covered with rubber shields.

Equipment.—Each engine has an air scoop, standard engine supports, exhaust flanges, engine lifting eyebolts, tool kit, and engine handbook. Other accessories that can be furnished include: hand cranking gear or direct cranking electric starter, Menasco starter drive assembly, fuel pump, generator and drive, hub assembly for wooden propeller, propeller hub for metal blades, magneto switch, and radio shielding.

INSTALLATION

Unpacking and Lifting.—Pirate C4 engines are supported in the shipping box on two sills and attached to them by four bolts through the mounting legs of the engines. The sills are bolted to the sides of the box by four bolts and are removable.

To unpack the engine, remove the cover which is attached with screws, attach a sling to the two eyebolts, taking care that the sling is long enough to prevent any excessive horizontal stress from occurring. Remove the four bolts attaching the sills to the box. Lift the engine vertically from the box and remove the sills.

Before installing the engine in the airplane,

1. Remove the spark plugs and turn the engine over 10 or 12 times to expel excess oil.
2. Wash the spark plugs in gasoline and see that they are clean before replacing them. Connect the spark-plug wires.
3. Wash the packing grease off the engine with gasoline. Do not use "dope" solvent, benzol, or alcohol mixtures, as they are paint removers. Avoid wetting the magnetos.
4. Remove the plugs from the oil fittings and the plates from the exhaust ports.

Fuel Supply.—Satisfactory operation of any aircraft engine is dependent upon the proper functioning of its accessories and particularly its fuel system. The capacity and location of the supply tank or tanks depend to a great extent on the design and type of the plane. Where the supply tanks are high enough above the carburetor to maintain satisfactory pressure and flow at the carburetor, the conventional gravity system is usually employed. In other cases an engine-driven fuel pump for normal operation and a manually operated hand pump for emergency operation should be used.

Current aircraft fuel systems may be classified under three general headings: (1) gravity system, (2) parallel pump system, (3) series pump system. These are shown in Fig. 8.

Gravity System.—In planes with this system, care should be exercised to guarantee fuel pressure and flow characteristics conforming to the basic requirements of the U.S. Bureau of Air Commerce, namely, "All fuel piping and fittings shall be of sufficient size so that under normal operation the flow is not less than double the normal flow required for full engine power."

For a conventional tractor type airplane with a gravity system, this means,

Full engine power is the *take-off* (*one minute*) power, at which the fuel consumption shall be assumed to be 0.60 pounds per horsepower per hour. Therefore, the constant 18,000 divided by this power equals the maximum permissible number of seconds for one gallon to flow at the carburetor inlet or bowl in order to meet the double flow requirement.

The required flow must be obtainable from any tank with low fuel. To determine this, the system must be dry and fuel should be added to one tank until a

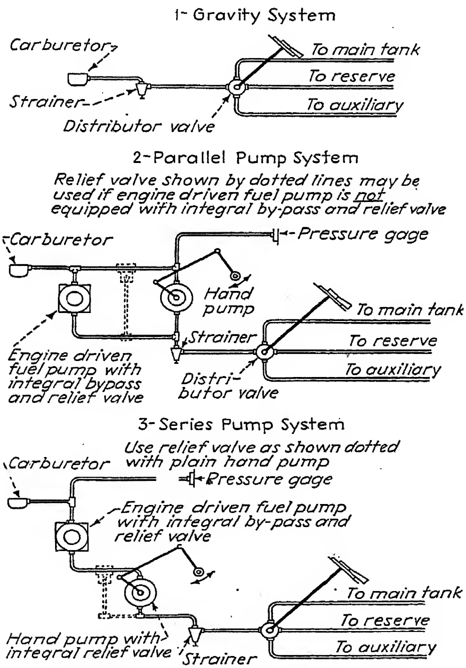


FIG. 8.—Three types of fuel feed systems.

steady flow is obtained at the carburetor inlet or bowl. Then one more gallon should be added to the tank and the number of seconds required for this gallon to flow should be determined. This procedure should be repeated with each tank with the system drained and dry before each test. Systems requiring an excessive initial amount of fuel to produce flow are unsatisfactory since they tend to airlock in service.

Airplanes will be tested on the ground in normal 3-point attitude or the best rate of climb attitude, whichever produces the most unfavorable angle for fuel flow.

Parallel Pump System.—Where the location of the fuel supply tanks is such that the foregoing gravity system requirements cannot be met, the parallel pump system is recommended. This has been highly successful. It has been used in a great number of military aircraft. Its simplicity and positive action warrant its serious consideration. As will be seen in Fig. 8, the parallel pump system requires a minimum amount of fuel piping and accessories. No by-pass valve is required for normal or emergency operation. A single relief valve, built integral with the modern engine-driven fuel pump, relieves the excess fuel handled by both the engine driven and manually operated hand pump.

Series Pump System.—This system was used extensively before the development of the parallel pump system and is given only as a matter of reference and record. It should only be considered as secondary to the parallel pump system. Its simplest form, as shown, demands the use of an engine pump with integral by-pass and relief valve as well as a hand pump with integral relief valve.

To deviate from this simple arrangement requires the use of separate by-pass and relief valve assemblies and necessary interconnecting piping, fittings, etc.

These U.S. Bureau of Air Commerce requirements apply to all aircraft employing fuel pump systems:

Aircraft using fuel pump systems will also be tested on the ground. The hand pump must prime itself quickly with low fuel in any tank and should supply the required double flow at the carburetor inlet or bowl with normal effort being applied to the pump operating lever by the pilot.

During the installation of all types of fuel systems the following points should be carefully observed:

All bends in fuel lines should be made over as large radii as possible.

All fuel lines should be made of seamless drawn soft copper or 4S0 seamless aluminum tubing.

All copper tubing should be fully annealed both before and after bending.

All fuel lines should be securely braced and protected from chafing against structural members. All sections of tubing not subject to vibration may be interconnected by means of approved type metal fittings or conventional hose connections.

All sections of tubing subject to vibration should be interconnected by means of rubber hose connections only.

Hose liners should be used at all hose connections to prevent particles of rubber from getting into the fuel lines.

Vertical bends should be avoided in all fuel lines to preclude possible air traps or locks.

The fuel supply shutoff cock or selector valve and the hand fuel pump should be located as close as possible to the carburetor or engine fuel pump. This minimizes the time required for fuel to reach the carburetor or pumps when switching from one supply tank to another.

All fuel lines should be of sufficient size to handle satisfactorily the quantity of fuel required for full power engine operation; $\frac{3}{8}$ in. O.D. tubing has been successfully used for engines up to and including 250 hp. Tubing sizes for engines of higher horsepower and fuel consumption should conform to current specifications (see below).

Current U.S. Army Air Corps specifications covering the size and wall thickness of aircraft fuel and oil system tubing are:

Tubing Sizes (Fuel System)	Max. Fuel Consumption, Gal. per Hr.
½ in. O.D. tubing	Under 60
⅝ in. O.D. tubing	60 to 100
¾ in. O.D. tubing	100 to 150

Tubing Wall Thickness (Fuel and Oil Systems)	Wall Thickness, Inch
Copper:	
¼ in., ⅜ in., ½ in., and ⅝ in. O.D	0.032
¾ in. and 1 in. O.D	0.049
Aluminum:	
¼ in. and ⅜ in. O.D	0.035
½ in. and ⅝ in. O.D	0.040
¾ in. and 1 in. O.D	0.049

Oil Supply.—The oil tank should be located near the pump, and if possible above the center of the engine. A large head, however, is not desirable since it may cause oil to leak through the pump, when standing for a long time, and fill the engine.

The oil tank should have a minimum capacity of 3½ gal. exclusive of expansion space, which should be equal to 10 per cent of the volume of the oil. In calculating oil capacity use a maximum oil consumption of 1½ pt. per hr. and allow a minimum of 2 gal. of oil in circulation.

The tank should be protected from the hot air coming from the engine and provision made to pass cool air continuously around it from the slip stream.

Ordinarily it is not necessary to install an oil cooler on the C4 engine. However, a cooler may be needed with certain types of installations or under unusual weather conditions. It should be inserted in the discharge line between the scavenging pump and the tank.

All oil pipe lines should be made of soft seamless drawn copper tubing, which must be annealed before and after bending, flaring, or other cold working operations. The lines should be short and have as few bends and connections as possible. Oil-resistant hose with liners should be employed at all connections. The lines should be well braced throughout their length to eliminate vibration.

The tubing to and from the engine should be ¾ in. diam. and never less than ½ in. diam. Smaller piping will give trouble in cold weather when the oil has a tendency to congeal.

The oil inlet connection is located on the right side of the oil pump and the oil outlet connection is on the left. These are fitted with nipples of proper size, beaded for hose clamps.

A ½ in. diam. vent pipe should be provided in the top of the tank and located in such a position that the oil will never close it during normal flight. If this can be arranged so that oil will not spill when the plane is being maneuvered, the vent pipe can be carried down and out the fuselage. Otherwise this pipe should be connected to the top of the accessory case, a ⅜-in. pipe tapped hole being provided for this purpose.

The oil strainer is at the lower left side of the accessory case. Provision should be made in the cowling and structure to get at this readily. The oil pressure relief valve is located on the right side of the oil pump near the oil inlet connection and should be made accessible.

The oil pressure gage connection is located on the rear of the accessory case and is tapped with ⅛-in. pipe thread. A ¼ in. O.D. copper tubing should be used to connect a 100-lb. gage. The oil thermometer connection is located on the left-hand side of the crankcase near the oil strainer. This is tapped for ⅝-18 threads. The thermometer should have a range to 212°F. (100°C.).

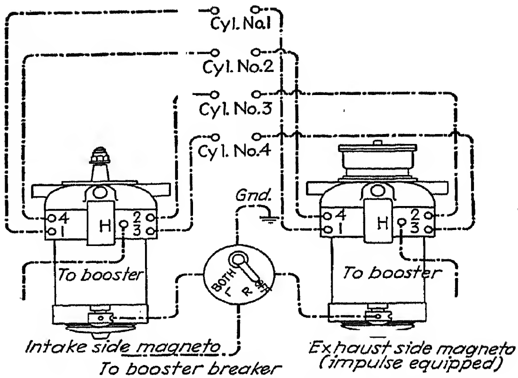


FIG. 9.—Wiring diagram of Menasco Pirate.

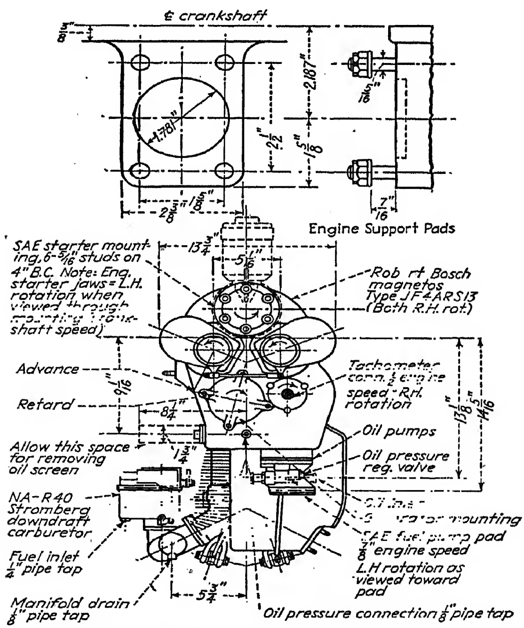
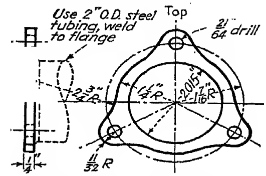


FIG. 10.—Dimensions for installation.

Magneto Wiring.—The wiring of the engine is shipped complete and should not be disturbed except to connect the two ground wires to the switch.

The knurled terminal at the back of the magnetos should be connected with insulated ignition wire to the points on the grounding switch marked "R Mag.," and "L Mag." The point marked "Grd." on the switch should be connected to the engine crankcase. These wires should all be clipped at suitable points to prevent them from chafing on the engine or engine mount.

The exhaust side magneto is equipped with an impulse starter to facilitate starting of the engine. Provision is made on magnetos for booster connections but a booster magneto is not essential with this equipment.



Steel Exhaust Pipe Flange
Engine furnished with 4 standard engine support brackets

If a booster magneto is used, the high tension lead should be connected to the terminal "H" on the top of either magneto. The ground wire from the booster magneto should be connected to the terminal marked "Booster" on the switch.

If the booster magneto is not mounted permanently in the cockpit, the body of the booster magneto should be grounded directly to the engine instead of through the switch. In this case the connection can be pulled out as soon as the engine starts and the magneto kept on the ground.

The spark control levers on the magnetos are connected by a rod. Provide for a movement of 25 deg. (see wiring diagram, Fig. 9).

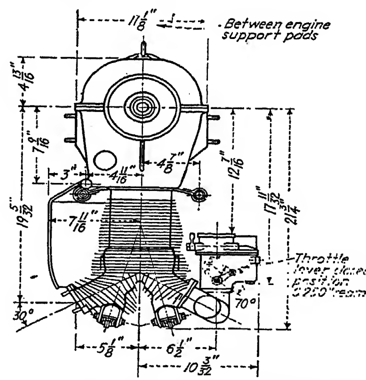


FIG. 11.—Installation drawing showing throttle connection.

Controls and Exhaust.—The location and movements of the throttle, mixture control, and spark timing control are shown on the installation drawing, Fig. 10. Other installation drawings are given in Figs. 11 and 12.

The exhaust pipe flanges furnished with the engine are intended to be welded to 2 in. O.D. steel tubing.

Tachometer Drive.—The engine tachometer shaft connection is an S.A.E. standard, threaded ⅞-18. It is located on the back of the accessory case near the right magneto. The driving spindle rotates *clockwise* looking at the open end and runs at *one-half* crankshaft speed.

A dual tachometer connection may be purchased from the Menasco Manufacturing Co. if desired.

Starter.—The starter usually used is the Eclipse Aviation Corporation's hand-cranking gear, type 4H4 or direct-cranking electric starter, type Y-150 or E-80, counterclockwise rotation. The starting crank for the former is

detachable and requires an outboard support or bearing where it passes through the cowling.

Generator.—Several types of battery charging or radio generators may be used. The ones usually used are the Eclipse Aviation Corporation's models, G-1 or LV-180, on the back end of the motor. (Clockwise drive end.)

Mounting Propeller.—The propeller should be carefully checked for balance and tracked before being placed on the engine. The crankshaft splines and thread should be lightly oiled before the hub is placed on the

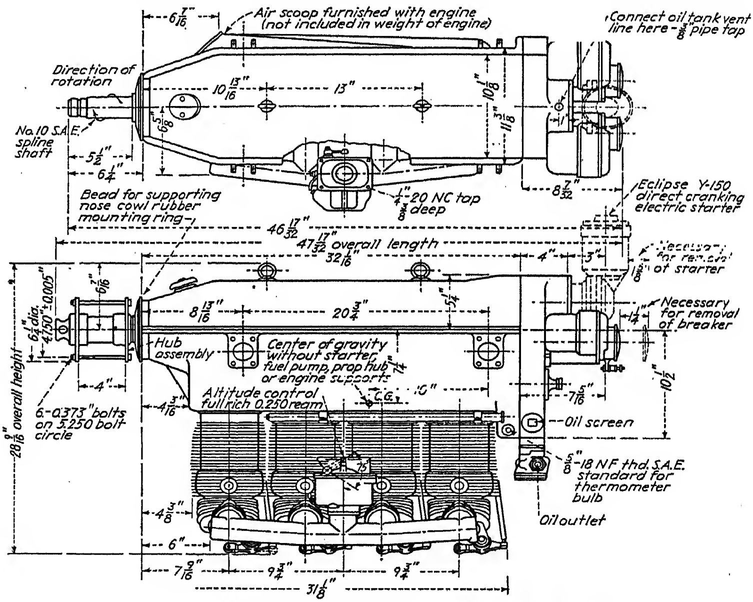


Fig. 12.—Lengthwise dimensions for installing Pirate engine.

engine. The propeller hub nut should be screwed up solid but should not be forced with a heavy sledge. Be sure to lock the nut to the crankshaft with the lockpin and cotter pin provided. Recheck the track after attaching the propeller to the engine.

The hub can be removed by backing off the same nut used to hold it in place; no other puller is required.

The propeller should be of such design as to hold the engine down to its rated speed, in level flight at sea level.

Cowling.—The C4 is equipped with a standard side air scoop. This type of scoop was evolved after much experimentation with engines operating both on the test stand and in flight test under very severe conditions. No other type of air scoop should be used.

The air is directed around the cylinders and heads to keep the temperature variation between cylinders not more than 5 per cent.

The air scoop is so proportioned that the engine cowling can be made extremely narrow without having to bump out for any interferences. The side air scoop opening in the nose cowling should be as nearly in line with the side air scoop as possible. A smaller opening of oval shape should be located in line with the cylinder heads for directing air over the central fins of the heads.

A common elliptical-shaped opening located on the vertical axis of the nose cowling to supply air for both side air scoop and cylinder heads is not recommended. This type, although perhaps of better appearance, has been discarded after numerous tests have proved that much better cooling is attained when the side air scoop opening is located to register directly with the side air scoop.

In the design of nose cowling, the following is recommended: provide one opening of 50 to 55 sq. in. in the nose cowling to register with the side air scoop and another opening of from 20 to 25 sq. in. for delivering air to the vertical fins of the cylinder heads.

Discharge louvers or an air exit scoop should be provided on the left side of the engine cowling. The discharge orifices should have an area 1½ times that of the nose cowling openings, or from 110 to 120 sq. in.

Several inlet louvers should be placed either in the nose cowling above the crankshaft or else on the top of the engine cowling near the front. Corresponding discharge louvers should be placed on top of the engine cowling at the rear in the vicinity of the oil tank. These louvers are for directing air over the crankcase and around the oil tank.

ENGINE TROUBLES

Determining the cause of engine troubles is at times rather involved on account of the number of sources to which a given symptom may be attributed. The best procedure is to take into account all possible causes and then eliminate them one by one, starting with the most likely. The most common troubles and their causes are given as an aid to service men and owners.

Causes of Non-starting. *Lack of Fuel.*—Examine the fuel supply, shut off the cocks, traps, strainers, and hose connection. Make sure there are no air locks in the line.

Water in the Carburetor.—Remove the fuel strainer, which is located near the fuel inlet, from the carburetor. Drain the water and clean the strainer.

Intake Manifold Leaks.—Examine the manifold for cracks. Inspect the gaskets and see that the flanges are pulled down tight and are not bent.

Throttle Opening Incorrect.—The throttle should be approximately one-eighth open or less to ensure a good suction on the metering jet.

Under or Overpriming.—The engine will require more priming when cold than hot. Overpriming will not injure the engine as any wet gas that is sucked into the cylinders will flow by gravity into the combustion head and out through the exhaust port. In this way the oil is never washed off the cylinder walls, thus preventing scoring and seizing of the cylinders and pistons. However, overpriming will make starting difficult. If the intake manifold becomes loaded, turn the ignition switch off, set the throttle wide open, and turn the engine *backward* several revolutions.

Impulse Starter Not Functioning.—The impulse starter, which is connected to the exhaust side magneto, should produce an audible click when the engine

is turned over slowly. If no click is audible, the pawls are probably not engaging or the springs are broken.

In extreme cold weather, the oil sometimes becomes so heavy that the pawls are prevented from dropping into place instantly. If this is the case, care should be taken to turn the propeller over slowly while starting to allow the pawls to engage the impulse starter.

If no click is heard after observing these precautions, the exhaust side magneto should be removed and the impulse starter inspected. Springs should be carefully inspected for breakage. See that the pawls engage properly with the catch plate.

Dirty Spark Plugs.—Clean the plugs and set the gaps.

Magneto Breaker Points.—See that the magneto breaker points are clean and have the proper gap. Test the spark delivered by the magneto.

Defective Ignition Wire.—Examine the ignition wiring for wear, breaks, grounds, and incorrect connections.

Incorrect Valve Tappet Clearance.—Adjust both intake and exhaust valve stems for 0.007 in. end clearance when the engine is cold.

Causes of Low Power and Rough Running.—The full throttle speed of the engine will vary 75 to 100 r.p.m. under different atmospheic conditions. It will also vary considerably with the condition of the propeller. Hence, it is essential that the engine be operated under similar conditions to ascertain whether there has been loss of power.

Rich or Lean Mixture.—Make sure the mixture control lever is in the best position.

Intake Manifold Leaks.—See page 225.

Ignition Trouble.—See that the spark is full advanced. Check the spark plugs, breaker points, and ignition wire.

Valve Mechanism Trouble.—Check the tappet clearance. It should not vary more than -0.000 in. $+ 0.002$ in. from desired cold clearance. Examine the springs, washers, ball ends, and push rods for breakage.

Pool Fuel.—Make sure that the fuel being used is a good grade of domestic aviation gasoline.

Loss of Compression.—Examine the cylinder-head gaskets for leaks. Make sure that hold-down stud nuts are tight. See that the valves are not warped and not sticking. Examine the piston rings for wear and tension.

Overheating.—This may be caused by mixture, leaks, ignition or poor fuel. It is indicated by the engine gradually dropping off in speed just after being brought up to normal speed from idling. Considerable damage is liable to occur from operating an overheated engine.

Other causes of overheating are: improper cowling, unsuitable oil, insufficient oil cooling, or restrictions in exhaust manifolding. See Causes of Excessive Oil Temperatures, page 227, and Causes of Excessive Cylinder Head Temperatures on the same page.

Propeller Flutter.—Rough running is very often caused by propeller flutter. The angle of the blades at given points should be carefully checked on a surface plate with a protractor. The propeller should then be balanced on a mandrel and tracked. The variance of the track should not be over ⅛ in. After this inspection, the blades should be observed for flutter while running at full speed on the ground. This condition may not exist at low engine speeds but becomes pronounced at full throttle. The substitution of a propeller from another engine which is known to run smoothly will sometimes be a convenient method of checking the cause of rough running.

Causes of Low Oil Pressure. *Lack of Priming.*—Disconnect the oil suction line and fill the pump with oil. Turn the engine over by hand until the oil is sucked into the pump. Check the oil supply.

Leak in Suction Lines.—Examine the oil suction lines for air leaks.

Oil Pressure Relief Valve.—Examine the oil pressure relief valve and spring for proper seating or breakage.

The oil pressure relief valve spring tension is set properly at the factory. No adjustment is provided for, as low oil pressure generally indicates trouble in the lubrication system which can not be corrected by a new adjustment of the relief valve.

The pressure can be regulated only by altering the tension of the spring, by changing either its over-all length or the pitch of the coils. The oil pressure should only be regulated when an oil having a different viscosity than recommended is necessary owing to unusual installations, airplane speeds, and climates.

Excessive Bearing Clearance.—If the oil pressure still fails to increase after having corrected for the above troubles, it is likely that the bearings are badly worn. The engine should be overhauled. See Complete Overhaul, page 228.

Causes of Excessive Oil Temperature. *Insufficient Oil Cooling.*—There should be a good circulation of air over the crankcase cover and around the oil tank.

Insufficient Oil Supply.—There should be at least 2 gal. of oil in circulation.

Improper Oil.—The oil should be of good quality and conform to recommended specifications.

Insufficient Oil Circulation.—If oil pressure is normal, examine the return line to the supply tank for leaks. Also inspect the gaskets on either side of the plate that separates the pressure and scavenging pumps to make sure that there are no leaks. Leaks of any consequence at either of these places should easily be detected.

Overheated Engine.—See Causes of Excessive Cylinder Head Temperatures, below, and Overheating, page 226.

Causes of Excessive Cylinder Head Temperatures. *Insufficient Cooling.* The engine should be cowled according to recommendations given under Cowling, page 224.

Lean Mixture.—A lean mixture may be caused by leaky gaskets or a cracked manifold. Examine the cylinder head gaskets and see that the hold-down stud nuts are tight. Check the intake manifold for cracks or bent flanges and inspect the gaskets to see that they are in good condition and are pulled down tight.

It may be necessary to enrich the mixture if the engine is being operated under unusual conditions. A pusher installation may require a richer mixture because of poor air flow. Also warm weather and slow air speeds may necessitate increasing the size of the main carburetor jet.

Retarded Spark.—See that the spark control lever permits ignition to be fully advanced.

Detonation.—Always use a good grade of domestic aviation gasoline. Special operating conditions may require the use of doped fuel.

Preignition.—Spark plugs with badly burned or carbonized points may cause preignition. The engine is supplied with the proper plug for average operating conditions. Excessive carbon deposits in the combustion chamber may also cause preignition.

Valve Leakage.—This may be due to warped valves or seats, excessively worn valves or seats, or badly worn guides or stems. This can be corrected by grinding, refacing, or replacing as the case warrants. On rare occasions valve leakage may be caused by the aluminum-bronze valve seat loosening in the cylinder head. This is unlikely unless the engine has been operated at abnormal temperatures.

Leaking Carburetor.—An engine should not be run if fuel leaks from the carburetor, because of the excessive fire hazard. This may be caused by (1) leaky float; (2) stuck float; (3) needle valve not seating; (4) wear in float fulcrum pin.

In any case the carburetor should be removed and checked over.

COMPLETE OVERHAUL

Under normal conditions, the engine should operate satisfactorily for 300 to 500 hr. before a complete dismantling and overhaul are necessary. Where the service is severe and the conditions abnormal, more frequent overhauls may be required. The need for a complete overhaul is usually indicated by a dropping off in oil pressure and full throttle revolutions, and an increase in oil consumption; also the finding of metal particles in the oil strainer may show the need for dismantling.

Preparation.—The engine should be removed from the plane. Before doing this, the propeller hub should be removed by pulling the locking cotter and pin and unscrewing the propeller hub nut. A steel bar ¾ in. in diameter and about 2 ft. long should be used. Lift the engine by means of a sling attached to the two eyebolts threaded into the crankcase cover. It should then be placed on an assembly stand and washed off with gasoline.

The best overhaul stand permits rotating the engine to any desired angle, so that mechanics can work on the engine in the most advantageous position.

As the parts of the engine are removed, they should be washed in gasoline (a spray is desirable) and placed on the inspection bench. The parts should be so grouped that they can be readily identified as to their original position on the engine.

The service tool kit furnished with each engine contains sufficient tools for general servicing. A few special tools will be needed for complete dismantling and reconditioning of the engine.

The information pertaining to both top and complete overhaul preparation should be consulted at this time for further details.

Dismantling.—It is assumed that the manifolds and cylinder units have been removed and dismantled in accordance with good engine practice and the engine is mounted in the inverted position.

Accessories.—Remove the ignition conduit assemblies from the engine by removing the distributor blocks from the magneto and loosening the clamps holding the conduits to the crankcase.

Remove the starter and magnetos before attempting to remove accessory case. If the magnetos are being removed for inspection only, with no intention of removing the accessory case, great care should be taken to prevent the micarta couplings from dropping into the accessory case sump. If the coupling is dropped there, it will be necessary to remove the accessory case to recover it.

Accessory Case.—See that the magnetos and starter have been removed before attempting to remove the case. Unscrew the capscrews and nuts that attach the case. The accessory case can now be removed by pulling it straight back, taking care not to disturb the location of the two dowels that

are pressed into the crankcase flange. Do not pry off the accessory case by inserting screw drivers under the gasket, as the machined surface is sure to be marred. It is designed with a raised bead, or flange, to facilitate loosening by lightly tapping the outer rim.

Crankcase Cover.—Remove the crankcase front plate by unscrewing the nuts and pulling the plate forward over the end of the crankshaft. Remove the bolts holding the crankcase cover to the crankcase. The crankcase cover can now be lifted vertically by the eyebolts. Be careful not to disturb the location of the dowels that are pressed into the crankcase flange.

If it is ever desirable to remove the crankcase cover only, it will not be necessary to remove the accessory case unit and accessories. This is done by using cap screws in the upper part of the accessory case and locating the dowels in the lower part. Care must be taken not to tear the accessory case gasket either in the removing or the placing of the cover.

Connecting Rod and Piston Assembly.—Remove the complete assembly from the crankcase before dismantling. Then remove the rings if they have not been removed already, following regular accepted practice. The pistons should then be removed from the rods by tapping the wrist pins out with a fiber drift. The pin should be a snug fit in the connecting rod at a room temperature of 70°F., and it is necessary to heat the assembly in hot water. **Caution.** *Never apply heat to the assembly with a torch, as cracks are likely to occur and the heat-treatment to be affected as a result of unequal and intense heating.*

Crankshaft.—Remove all main bearing cap nuts. Remove all bearing caps except the one adjacent to the propeller thrust ball bearing.

The crankshaft should now be lifted vertically, the bearing cap being removed at the same time. The bronze-backed bearing shells may adhere to the shaft and be lifted from the crankcase. Care should be taken to prevent them from dropping and becoming damaged.

Magneto Gears.—Remove the wire ring, using a screw driver to spring it over the groove. In doing this, be careful not to open the ring too wide and cause it to lose its tension. Remove all burrs from the end of the shaft before removing the gear from the crankcase.

Tappets and Guides.—Remove the nuts holding the tappets in place and pull the assembly out. It is possible to remove both the tappet and the guide together as the roller will clear the guide hole in the case (see Fig. 13).

Camshaft and Gear.—First remove the camshaft nut and the camshaft gear, using a gear puller. The gear is provided with two holes in the web for that purpose. The holes are 2 in. apart and are tapped $\frac{5}{16}$-24 (see Fig. 14).

The camshaft thrust bearing retainer should be removed next and then the camshaft can be pulled out. Be sure that the tappets and guides have already been removed.

Oil Pump.—Unscrew the four nuts and remove the pump from the accessory case. Remove the lower or pressure pump body, care being taken not to loosen the two gear shafts that are pressed into the housing. Remove the pressure pump driving gear and Woodruff key from the shaft. The separating plate can now be removed. Remove the scavenging pump driving gear and Woodruff key from the shaft. The pump can now be completely dismantled.

Starter Drive Gear.—The starter jaw must be removed first. The jaw is supported on splines and secured by a cap screw. After removal of the jaw, the rest of the assembly can be readily removed from the case and dismantled.

Rocker Arm Assembly.—Remove the cotter pin and nut from the rocker arm shaft and then drive the shaft out with a fiber drift. The rocker arm can now be removed. The ball bearings can be removed from the rocker arm by tapping on the inside face of the inner race.

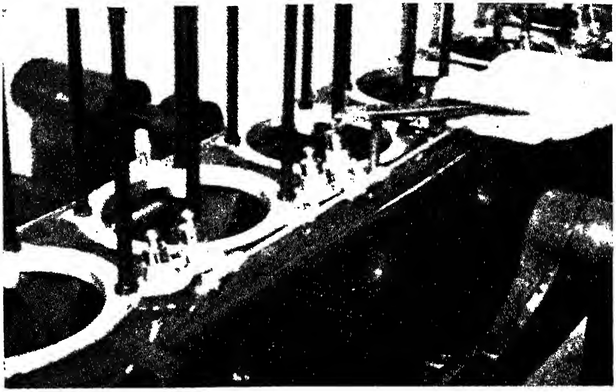


Fig. 13.—Removing tappets from crankcase.

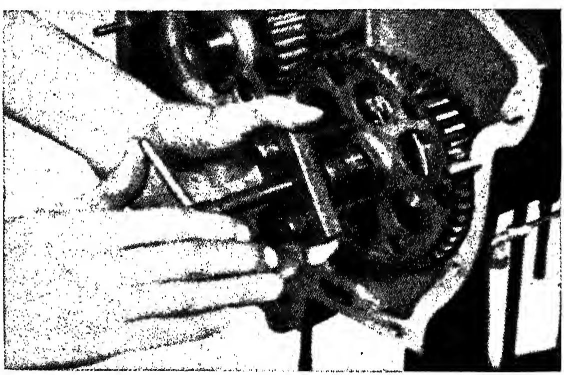


Fig. 14.—Pulling the camshaft gear.

Inspection and Repair.—After the engine has been completely dismantled and the parts thoroughly cleaned and placed upon the inspection bench, a careful inspection of these parts should follow. Valve grinding, inspection, and replacement of piston rings and cylinder-head gaskets are performed in the regular manner.

Maximum Service Clearances.—The maximum and minimum service clearances allowed in manufacturing, as well as the maximum clearance allowable in service before a part must be replaced, are shown in Table 2. The

last column shows maximum wear permissible. These figures must not be construed to mean that any part showing less wear is in satisfactory condition. The appearance of a part is frequently a much better indication than are the dimensions. The figures in the last column are merely guides where looseness is the sole consideration. When clearances are found in excess of these figures, an investigation should be made to determine the cause. This can very often be traced to the wear or failure of some other part.

Replacements.—All parts that do not measure up to the dimensions given in the last column should be replaced. All parts that are cracked, deeply scratched, or pitted should be rejected regardless of whether the dimensions are within the limits or not.

Always number each new part to correspond to the number on the old part that is replaced.

Experience has indicated that in many cases ball bearings are replaced on overhaul when it is not necessary or desirable. This is due mainly to two causes: (1) failure to appreciate that all ball bearings loosen up considerably during the first few hours of running, after which the degree of looseness remains practically unchanged for an indefinite period. The ball bearing after just 50 hr. of service will invariably feel considerably looser than a new bearing of the same type. This, however, should not in itself be considered cause for replacement. (2) Another cause of unnecessary rejection is improper methods of inspecting bearings for roughness due to worn balls or races. If a ball bearing is thoroughly washed in gasoline and allowed to dry, all traces of lubricant are removed from the bearing and it will almost invariably feel rough when inspected in this condition. A few drops of oil should be placed on the balls and the bearing checked for roughness or unevenness by spinning the outer race and noting the feel of the bearing. If there are any serious defects in the balls or races, the small amount of oil applied will not prevent their detection.

Studs.—In replacing a stud, select an oversize part, put white lead on the threads, and turn it into place to a height corresponding to that of similar studs.

Crankcase.—Carefully inspect the crankcase for cracks, chafing at the parting flanges, and interference with moving parts. See that the locating faces of the cylinder flanges are smooth. All studs should be tight. Do not remove camshaft bushings except for replacement.

In replacing camshaft bushings see that they are located so that the oil hole drilled in place through the oil catch basin will intersect with the oil groove of the bushing. Both the oil hole and locking cap-screw hole must be drilled after bushings are in place. The bushings should be line-reamed in place, special equipment being required.

If the magneto gear bearings in the crankcase are rough, a reamer can be used to smooth them up. The magneto gears, if rough, should be smoothed with a fine stone before being replaced in the crankcase.

The main bearings should be examined for wear, cracking, or bad adhesions of lining. *If the bearings are worn, the caps must not be filed off to allow the bearings to clean up*, but should be replaced. The bearings are designed so that no filing or scraping is necessary. However, when replacing a bearing the "pinch" of the bearing cap on the new bearing should be checked. This can be done as follows:

After the bearings are in place, the nuts holding the cap should be drawn down tightly. Then loosen one side and with the other side drawn tight,

check the gap between the bearing cap and crankcase on the side that has been loosened. This gap should be from 0.004 to 0.006 in. and can be checked with a feeler gage. If more than this amount is shown, the edges of the bearing shell should be dressed down on a piece of emery cloth resting on a surface plate. Be sure that no emery clings to the bearing when reinstalling it. In case the "pinch" is less than 0.004 to 0.006 in. another set of bearings should be tried. The "pinch" is determined before the shaft is installed.

Accessory Case.—Detach the tachometer drive bushing and remove the two bevel gears. Inspect both bushings for wear and smoothness. If it is necessary to replace the bronze bushing, it can be driven out with a metal drift and hammer. The new bushing should be reamed to size, in place.

In assembling the tachometer drive bushing, be careful that the oil hole is toward the top.

Cylinder.—Cylinders should be examined for taper and roundness by the use of an inside micrometer. Cylinders tapered or out of round more than 0.003 in. should be replaced. The bore should be inspected for smoothness and any scores or rough spots removed with a smooth round stone. See that the cylinder flange and the end of the cylinder pilot that bear against the crankcase and head gasket respectively are smooth.

Cylinder Head.—The rocker arm should be inspected to see that it is free but it should have no perceptible looseness in the bearings. The rocker arm shaft should be tight in the bushings. If there is any looseness here, the rocker arm shaft bushings should be replaced. This can be done by driving out the old bushings with a metal drift and hammer. The new bushings should be reamed in place.

Inspect the cylinder-head gaskets carefully.

Inspect the valve seats for tightness; if they are loose, the cylinder head should be returned to the factory for replacement of seats.

Inspect the spark-plug insert bushings for proper thread size and tightness of the bushing in the head. If the bushing is loose, drill out the pin holding it in place. Then remove the bushing, taking care not to gall the threads. Replace with an oversize bushing, coating the threads with white lead or castor oil. Then drill a new pin hole and repin. In drilling out the old pins and drilling for the new pins, be careful not to go too deep. This pin is $\frac{1}{8}$ in. diam. and $\frac{5}{16}$ in. long.

The valve guides should be inspected for tightness in the cylinder head. If loose, replace them with an oversize part. Check the clearance of each valve in its guide, replacing any guide in which the valve has clearance over the maximum limits specified on page 240. The valve stems themselves seldom wear, but if the stem is rough, the diameter should be checked and the valve replaced if it seems necessary.

The guides can be readily pressed out with the aid of an arbor press and metal drift. Support the head on a short piece of tubing placed concentric with guide. Inspect the hole in the head and be sure that it is clean and smooth before replacing the guide; if rough, ream lightly and remove all burrs. Check the diameter of the new guide and make sure the right amount of shrinkage will be obtained as shown on the chart.

The new guides should be smeared with white lead or castor oil and pressed into place, using an arbor press and metal drift.

The clearance of the valve in the new guide should be checked against the clearance chart and the guide reamed out, if necessary, using an expansion reamer.

Rocker Arms.—Inspect the rocker arms for cracks, wear of the roller and its pin, and binding of the ball bearings. Examine the ball end adjusting screw for wear and cracks.

Push Rods.—Inspect the push rods for cracks, wear, and lack of straightness. Examine the push rod cup ends to see that they are tight on the push rod and are wearing evenly.

Tappets and Guides.—The tappets should be inspected for cracks and for looseness in the guides. The roller, pins, and ball ends should be examined for wear.

See that the guides fit tightly in the crankcase.

Crankshaft.—The crankshaft should be removed and all oil passages thoroughly cleaned. Examine the shaft for cracks, check the threads and splines for nicks and burrs, and see that the bearing surfaces are smooth.

The threads and splines can be smoothed with a fine stone or file and ordinary roughness can be removed from the bearing surfaces with a strip of fine emery cloth and then polished with crocus cloth.

Connecting Rods.—Examine the connecting rods for cracks and lack of straightness. If the wrist pin has excessive clearance, it should be replaced with an oversize pin and the rod and piston reamed to fit.

Examine the bearings for wear, cracking, or bad adhesions of lining. If the bearings are worn, the caps must not be filed off to allow the bearings to clean up but should be replaced. The bearings require no fitting, other than a possible cleaning up at the ends where the bearing meets the fillet of the crankpin. Sometimes a little scraping is required here. The "pinch" should be checked as for crankshaft bearings on page 239. Allow 0.001 to 0.003 in. "pinch."

Wrist Pins.—Wrist pins should be checked for cracks and scores. Cracked pins must be replaced; if the scoring or wear is not too great, roughness can be removed with a fine stone.

Pistons.—The pistons should be examined for scores, cracks, and erosion. If cracked or severely eroded, the piston should be replaced. Light scores and rough spots can be removed with kerosene and a fine stone. The new piston must not differ in weight more than 0.03 lb. (½ oz.) from the one it replaces.

Gears.—All gears should be inspected for cracks, nicks, roughness, and wear on teeth. If the fault is not serious, the teeth may be smoothed with a fine stone. Gears with cracked, worn, or missing teeth must be replaced.

Assembling. *Precautions.*—The successful operation of the engine is entirely dependent upon the attention given to every detail in the inspection and the assembling of the engine. Both inspector and mechanic should remember that the slightest neglect on their part may result in the failure of the engine.

Cotter pins and safety wire should never be used a second time. Other safety features which have been bent or worn should be replaced with new parts.

Great care should be taken to prevent dirt, dust, cotter pins, nuts, washers, and other small particles from falling into the engine while assembling. These can work into the gears or oil lines and cause considerable damage.

Before their assembly in the engine, all parts should be carefully cleaned. The use of a gasoline spray for this purpose is strongly recommended as rags or waste leave lint that may clog oil lines and strainers.

Completely finish each step in the process of assembling as the work progresses. Do not leave a bolt loose or a nut uncottered with the idea of coming back to it later. You may forget or someone else may be called upon to finish the job and he may not know of your intentions.

In assembling ball bearings, always be sure that the races are located in the same relation to the washers or the surfaces upon which they bear, as before. Most bearings have identification marks engraved on the faces of the races which in time cause the surface in contact to become slightly raised, leaving an impression of the markings.

Coat all surfaces of moving parts thoroughly with oil, as it takes considerable time for the oil to reach all parts after the oil pump is in operation. Also all parts that are a drive or push fit should likewise be coated with oil to facilitate their assembly in the engine. In the assembling procedure following, it will be assumed that the foregoing recommendations and precautions have been applied.

The engine should be assembled in the following order:

Crankshaft.—The propeller thrust ball bearing should either be removed from the crankshaft or driven forward about 1/8 in. from the locating flange of the shaft. The crankshaft should then be laid in the crankcase, the bearing caps put in place, and the nuts slightly tightened. Next locate the propeller thrust bearing washer so that the lug is in line with the 1/8 in. diameter hole in the top of the bearing cap. Then tighten the propeller thrust bearing nut firmly, being sure that the washer seats properly and the lug drops into place. Next tighten the main bearing cap nuts firmly and lock with wire, being sure that crankshaft turns freely.

Camshaft.—Place the camshaft in the crankcase and attach the thrust ball-bearing retainer with the cap screws. Be careful in lock-wiring these cap screws that the wire is placed so as to be in the clear of the camshaft gear. Next mount the camshaft gear, lock washer, and nut, and lock the nut with the lock washer.

Valve Timing.—The right magneto gear should first be put in place. Both magneto gears are interchangeable both as to dimensions and timing markings. The gears, however should be placed in their original positions to ensure proper alignment. The "0" marks are for locating the camshaft for correct valve timing. The "x" marks are for the purpose of locating the left magneto gear for ignition timing.

Rotate the crankshaft and camshaft in such a position to enable dropping the right magneto gear in place with its "0" marks registering with those of the crankshaft and camshaft gears. *Do not be confused with the two "x" marks as they are used only for locating the left magneto gear.*

Next rotate the crankshaft in a position to allow the left magneto gear to be dropped into place with the "x" marks registering with those of the crankshaft gear.

The proper location of the gears is shown in Fig. 15.

The wire snap rings should be snapped into the grooves of the magneto gears, care being taken not to spring them open wide enough to lose their tension.

The timing gear train is now assembled and the engine is in time, except for the proper location of the magnetos. The magnetos can be timed after they are mounted to the engine by means of the magneto timing pointer supplied with each engine (see page 237).

This pointer may also be used to check the valve timing as the position of inlet valve opening 1 is indicated on the crankcase front plate and occurs at

17 deg. before top center, with the engine cold and 0.007 in. tappet clearance.

Tappets and Guides.—The tappets and guides may be assembled in a unit, as the guide hole in the crankcase is large enough to allow the tappet roller to clear. See that the palnut lock nuts are in place.

Connecting Rods and Pistons.—The connecting rods and pistons should be assembled by heating the pin end of the rod in boiling water. The piston pin holes in the piston should be well oiled and the pin started in one side. When the rod is heated, the pin hole should be oiled and then with the rod held in position, push the pin through. Centralize the pin by tapping with a rawhide mallet before the rod cools. Care should be taken in assembling the rod and piston to see that they are in the same position as before dismantling. That is, the numbers on the rod should be on the camshaft side of the engine and the numbers on the piston toward the propeller end of engine.

In a complete overhaul or whenever the piston and rod are removed from the engine, it is best to assemble the rings on the bench before reinstalling the piston and rod. Otherwise follow the instructions given on page 233.

Place the connecting rod and piston assembly on the crankpin, tighten the nuts firmly, and cotter-pin them. Be careful not to screw the nuts too tight and cause the bearing caps to distort and pinch the crankpin.

Crankcase Cover.—The crankcase cover should be attached to the engine using palnuts for locking the plain nuts. Then mount the crankcase front plate so that the edge marked "Top" is above. Be sure that the nuts are drawn up tight and safety wired.

Accessory Case.—First attach the oil pump to the accessory case. Tighten the nuts evenly and be sure that the pump bodies are in alignment. The oil pump and gear train should be checked for alignment by inserting a screw driver in the end of the tachometer drive shaft slot and rotating it. The train of gears should turn freely; if they do not, the oil pump should be investigated. Loosen the nuts attaching the oil pump assembly and tap the sides of the housings lightly to bring them in alignment, so that the gears turn freely. Tighten up on the nuts and, if the gears still turn freely, the pump is in alignment.

After the train of gears turns freely, the accessory case should be mounted, care being taken not to cock the case to one side. Insert a screw driver into the tachometer driveshaft and turn the gear so that the tongue will drop into the slot provided at the end of the camshaft. Care should be taken to see that the dowel holes line up with the dowels.

Piston Rings, Cylinders, and Cylinder Heads.—Refer to page 232 for proper procedure in assembling these units.

Magneto Oiling.—Proper oiling is of vital importance for satisfactory operation of the magneto. Use the best grade of medium oil obtainable.

After 24 hr. of operation put from 30 to 40 drops of oil in the front oil hole or until it appears at the overflow hole for the distributor gear axle bearing. This hole is located about 1 in. below the front oil hole cover.

Put about 3 to 5 drops of oil in the back oil hole. *Never apply more oil than this at one time* as too much would flood the breaker compartment and might foul the contact points.

Magneto Contact Points.—The life of the contact points depends to a large extent on how clean they are kept. Clean them at least after every 25 hr. of operation. File them only when it becomes absolutely necessary for the best operation of the magneto. *Do not use emery cloth.*

The gap between contact points when fully opened should be maintained at 0.012 in. Use the gage on the magneto wrench for this purpose. Keep the points in alignment.

Magneto Timing (Scintilla Magnetos).—Magneto direction of rotation and right and left distributor blocks are designated as viewed looking at the drive end of the magneto shaft. *The magnetos will be designated as intake and exhaust, instead of left and right,* to avoid confusion.

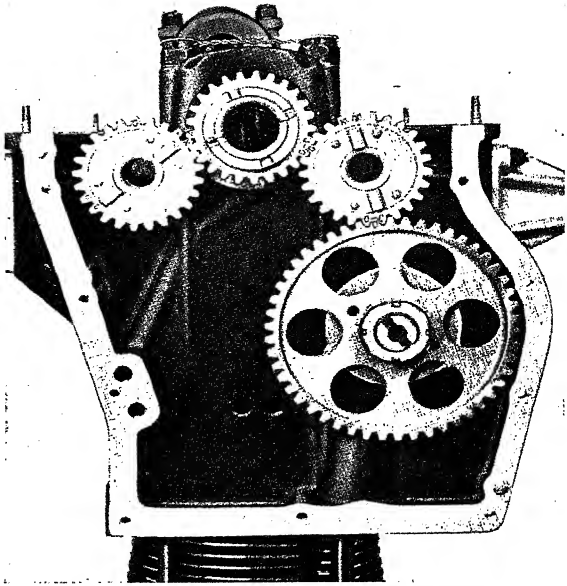


FIG. 15.—Locating timing gears for both magnetos.

The magnetos are interchangeable except for their couplings, as they both rotate in the clockwise direction.

The exhaust side magneto is equipped with an impulse starter or coupling. This coupling is located properly on the magneto shaft when the keyway marked "R" is used.

The distributor blocks and the breaker covers should be removed from both magnetos to enable setting them in the proper position for coupling to the engine.

There are two sets of markings on the magneto front end plate consisting of one line adjacent to the left distributor block and two lines adjacent to the right distributor block. Similar markings are on the distributor gear.

The magnetos are in correct position for coupling to the engine when these two groups of markings coincide with each other, as electrode 1 on the right distributor block is then in position for firing.

The gears in the timing train should be checked before attaching the magnetos to make sure that they are assembled properly. *The exhaust side magneto gear must be in proper location if the valve timing is correct*, but the intake side magneto gear may not be and should be checked at this time. Refer to page 236 and Fig. 15.

The crankshaft must be rotated until piston 1 is on the compression stroke (both valves closed) before attaching the magnetos.

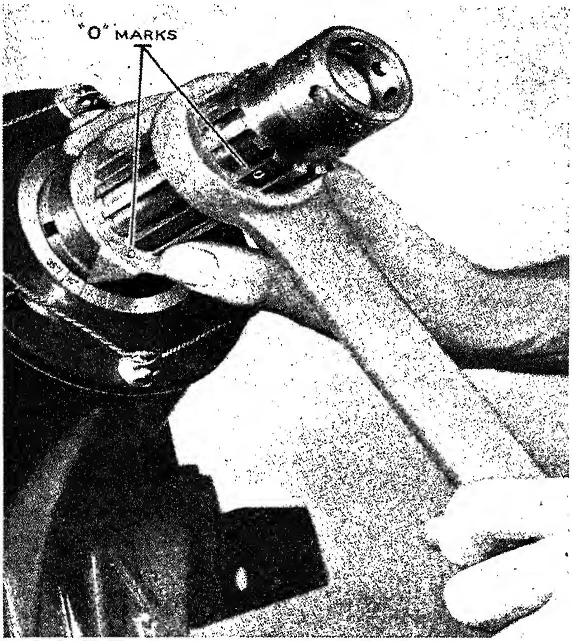


FIG. 16.—Using the magneto timing pointer on the crankshaft.

Take care when attaching the magnetos to the accessory case that the micarta couplings do not drop into the sump. Smearing the couplings with grease will help prevent this.

The coupling should be placed on the end of the gear and the magneto coupled to it. Complete the assembly of one unit before attaching the other micarta coupling to the gear as it might be jarred off.

The magnetos are timed in the following manner:

Place the magneto timing pointer on the crankshaft end with the "O" markings on the pointer and spline in alignment (see Fig. 16).

A strip of cigarette paper or a 0.001-in. feeler should be placed between the magneto contact points to help determine the position where they open.

The intake side magneto should be set to break at 30 deg. before top center when fully advanced.

Rotate the crankshaft in the counterclockwise direction until the pointer coincides with the line marked 30 deg. on the crankcase front plate.

Fully advance the breaker assembly and rotate the body of the magneto until the paper between the points can just be pulled out. After the setting has been checked several times, the magneto should be clamped tight to the accessory case and the nuts locked with safety wire.

The exhaust side magneto should be coupled to the engine in a similar manner. It should be set to break at 35 deg. before top center when fully advanced.

It is necessary that the pawls of the impulse coupling are disengaged before setting this magneto. They can be released by rotating the crankshaft counterclockwise (propeller end) past top dead center until the impulse coupling snaps. The crankshaft should then be rotated in the opposite direction until the pointer is a little past the line marked 35 deg.

The magneto gear may now be set in proper location by rotating the crankshaft in the counterclockwise direction until the pointer registers with the marking 35 deg.

This is done to eliminate the error caused by the backlash in the gears. The same precaution should be exercised in setting the intake side magneto.

The magnetos are now ready for wiring and the diagram shown on page 222 should be consulted.

The numbers on the distributor blocks show the serial firing order of the magneto. The numbers on the top of the main cover are for the purpose of locating the right and left distributor blocks to their respective sides.

Note that wire 1 on the distributor block goes to cylinder 1 (adjacent to propeller end) or first cylinder in the firing order of the engine, while No. 2 on the distributor block goes to the second cylinder in the firing order of the engine which is No. 3, etc.

The firing order is 1-3-4-2.

Special attention should be given that full advance and retard are obtained when the spark lever in the cockpit is moved to its full advance and retard positions. Refer to page 222 for the diagram used in wiring magneto switches and boosters.

If a battery ignition is employed, or magneto other than Scintilla, instructions necessary will be furnished by the maker.

Spark Plugs.—The plugs should be cleaned and washed in gasoline and the gap adjusted to 0.015 to 0.018 in.; 0.015 in. is desirable.

Valve Clearance Adjustment.—Refer to page 213.

Running in.—Before attempting to start the engine, the items listed under Engine Troubles, page 225, should be noted.

After a complete overhaul, the engine should be run in just as carefully as though it were new. The engine should be run in for a period of at least 2 to 3 hr. at gradually increasing speeds. Additional run-in time depends upon the number and nature of the parts replaced and rests largely with the judgment of the operator. New pistons, piston rings, and cylinders require the most run-in time.

A minimum of 5 hr. total is recommended when several of these parts have been replaced.

This also applies to testing engines which have been given a complete overhaul.

Permissible Clearances between Wearing Parts.—In order to secure good service from any engine, it is necessary to maintain the bearings within limits that experience has shown to be desirable. Figure 2 shows a section of the

Table 2.—Wear Limits

Part	From	Desired	To	Maximum allowable wear
Crankcase front plate and crankshaft thrust bearing nut, diam	0.008L*	0.008L	0.012L	0.025L
Crankcase front plate and crankcase cover, diam	0.001L	0.001L	0.005L	
Crankshaft thrust bearing and crankshaft, diam	0.0002T	0.0004L	0.0007L	
Crankshaft main bearings and crankshaft, diam	0.001L	0.002L	0.003L	0.006L
Crankshaft main bearings and crankcase, diam	0.002T	0.0025T	0.003T	
Crankshaft main bearings and crank cheek, end clearance	0.1725L	0.1875L	0.2025L	
Connecting rod bearing and crank cheek, end clearance	0.003L	0.007L	0.008L	0.025L
Connecting rod bearing and crankpin, diam	0.001L	0.0015L	0.0025L	0.005L
Connecting rod bearing and connecting rod, diam	0.0005T	0.0015T	0.0015T	
Starter drive bearing cap and front bearing, diam	0.0005L	0.000	0.0005T	
Starter drive gear and front bearing, diam	0.0002T	0.0002T	0.001T	
Starter drive bearings with housings, end clearance	0.0016L	0.0016L	0.0206L	
Starter drive gear and rear bearing, diam	0.000	0.0002T	0.001T	
Accessory case and rear bearing, diam	0.0005L	0.000	0.0005T	
Starter drive gear and crankshaft gear, backlash	0.002	0.004	0.006	0.018
Accessory case and starter, diam	0.003L	0.003L	0.008L	
Accessory case and magneto, diam	0.000	0.000	0.003L	
Magneto gear bushing and magneto gear hub:				
End clearance	0.0045L	0.0045L	0.0195L	
Diam	0.0015L	0.0015L	0.0035L	0.006L
Magneto gear bushing and crankcase, diam	0.001T	0.002T	0.003T	
Magneto gear with crankshaft or camshaft gears—backlash	0.002	0.004	0.006	0.018
Camshaft bearing and crankcase, diam	0.0005T	0.001T	0.0025T	
Camshaft bearing and camshaft, diam	0.001L	0.0015L	0.0025L	0.005L
Camshaft thrust bearing and crankcase, diam	0.0006T	0.0001T	0.0005L	
Camshaft thrust bearing and camshaft, diam	0.000	0.000	0.0009T	
Camshaft gear and camshaft, diam	0.0005L	0.000	0.0005T	
Key—camshaft—in shaft, side clearance	0.000	0.000	0.002T	
Key—camshaft—in gear, side clearance	0.000	0.001L	0.002L	
Camshaft and oil pump driving bevel gear, side clearance	0.009L	0.010L	0.012L	0.020L
Valve tappet roller pin with tappet or roller, diam	0.001L	0.001L	0.002L	0.006L
Valve tappet roller pin and guide, end clearance	0.0255L	0.0255L	0.031L	
Valve tappet roller and tappet, side clearance	0.016L	0.016L	0.026L	
Valve tappet roller and guide, side clearance	0.001L	0.003L	0.005L	
Valve tappet guide and valve tappet, diam	0.0005L	0.0005L	0.001L	0.002L
Valve tappet guide and crankcase, diam	0.0006L	0.000	0.0006T	
Valve tappet and ball end, diam	0.0005T	0.001T	0.0015T	
Push rod cup end with rocket or tappet ball end, diam	0.000	0.000	0.004L	0.010L
Push rod cup end and tube, diam	0.002T	0.002T	0.004T	
Push rod pin with cup end or tube, diam. (before riveting)	0.007L	0.000	0.002T	
Tachometer connection bearing and accessory case, diam	0.001L	0.001L	0.004L	
Tachometer connection bearing and oil pump driving bevel gear, diam	0.001L	0.001L	0.008L	0.006L
Tachometer connection bearing and oil pump driving bevel gear, total end clearance	0.005L	0.010L	0.015L	
Oil pump driving and driven bevel gears, backlash	0.002	0.004	0.006	0.018
Oil pump driven bevel gear and bushing, total end clearance	0.008L	0.016L	0.024L	
Oil pump driven bevel gear bushing and accessory case, diam	0.0005T	0.001T	0.0015T	

* The letters L and T mean "loose" and "tight" by the amount shown.

Table 2.—Wear Limits (*Continued*)

Part	From	Desired	To	Maximum allowable wear
Oil pump bevel gear and bushing, diam.....	0.001L	0.001L	0.003L	0.006L
Oil pump driven bevel gear and oil pump drive shaft, clearance across flats of square end..	0.001L	0.002L	0.003L	
Oil pump upper case and accessory case, diam	0.000	0.000	0.002L	
Key—oil pump drive shaft:				
In shaft, side clearance..................	0.002T	0.001T	0.000	
In gears, side clearance..................	0.000	0.001L	0.002L	
Oil pump scavenger or pressure gears with oil pump cases:				
Side clearance.	0.003L	0.003L	0.005L	0.010L
Diam..................................	0.001L	0.001L	0.004L	
Oil pump scavenger and pressure gears, backlash..................................	0.002	0.004	0.006	
Oil pump drive shaft with oil pump scavenger or pressure gears, diam............	0.0005L	0.0005L	0.002L	
Oil pump upper case and pins, diam	0.0005T	0.000	0.0015L	
Oil pump gears and pins, diam......	0.001L	0.001L	0.0023L	0.005L
Oil pump lower case and pins, diam......	0.002T	0.001T	0.000	
Oil pump drive shaft and oil pump cases, diam..................................	0.0005L	0.001L	0.002L	0.005L
Oil pump lower case and oil pressure relief seat, diam............	0.003T	0.003T	0.004T	
Piston ring:				
Tension..............	8 lb.	10 lb.	11 lb.	5 lb.
Gap.................	0.020	0.025	0.030	0.040
Crankcase and cylinder.................	0.000	0.000	0.002L	
Piston pin and piston, diam. (hand push fit at 70°F.)...........................	0.0002T	0.000	0.0002L	0.005L
Piston pin and connecting rod, diam......	0.001T	0.0005T	0.000	0.005L
Piston pin and plug, diam..............	0.0025T	0.002T	0.0005T	
Piston pin and cylinder, end clearance....	0.020L	0.035L	0.051L	
Piston and cylinder:				
Lower land, diam....................	0.055L	0.055L	0.058L	
Skirt, diam.........................	0.0235L	0.024L	0.0255L	0.040L
3d land, diam........................	0.027L	0.028L	0.030L	
2d land, diam........................	0.033L	0.034L	0.036L	
1st land, diam.......................	0.039L	0.040L	0.042L	
Cylinder and cylinder head, diam........	0.002L	0.002L	0.006L	
Rocker bushing and rocker bearing shaft, diam.	0.001L	0.001L	0.002L	
Rocker and bearings, diam.................	0.0006T	0.0006T	0.0003L	
Rocker bearing shaft and bearings, diam.....	0.0004T	0.0007L	0.0012L	
Rockers and bearings, total end clearance....		Draw up snug		
Rocker roller and sleeve, diam..............	0.002L	0.002L	0.0035L	0.020
Rocker roller and rocker, side clearance......	0.016L	0.016L	0.022L	0.030
Rocker roller sleeve and pin, diam..........	Select for		0.0005	tight fit
Cylinder head and valve guide—intake and exhaust, diam..........................	0.001T	0.0015T	0.0025T	
Valve and valve guide:				
Intake, diam..........................	0.003L	0.003L	0.0045L	0.012L
Exhaust, diam.........................	0.004L	0.004L	0.0055L	0.015L
Cylinder head and valve seat...............	0.008T	0.008T	0.010T	
Piston and piston ring, 1, side clearance......	0.007L	0.008L	0.0095L	
Piston and Piston Rings:				
No 2, side clearance......................	0.005L	0.006L	0.0075L	
No. 3, side clearance.....................	0.003L	0.004L	0.0055L	
Oil Scraper, side clearance...............	0.002L	0.0025L	0.0035L	
Piston and piston rings—radial clearance between ring and bottom of groove........	0.022L	0.030L	0.042L	

Pirate engine. The desired and the permissible clearances of these parts, given in Table 2, should be of great value in maintaining these engines in good condition.

SECTION VII

RANGER ENGINES

The Ranger is a six-cylinder, air-cooled line engine. Two views are shown in Figs. 1 and 2. The cylinders are inverted, are not supercharged, and have the propeller mounted directly on the crankshaft. It is built by Ranger Aircraft Engines, a division of the Fairchild Engine Airplane Corp., Farmingdale, L.I., N.Y. Details follow.

Crankcases.—The main crankcases are of cast aluminum alloy, with upper and lower sections parted at the crankshaft center line. Both sections are ribbed for seven main bronzed backed, babbit-lined bearings. They are clamped together by long studs anchored in the upper webs and extending entirely through the lower webs and crankcase.

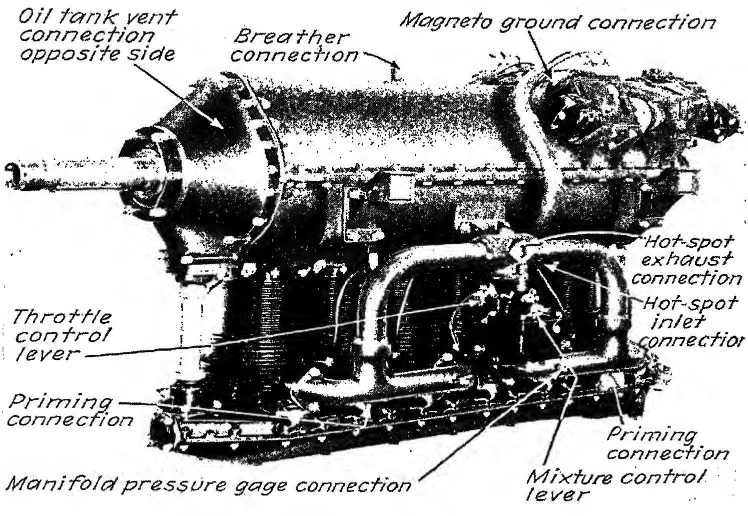


Fig. 1.—Left side of Ranger engine.

The front crankcase section carries the propeller thrust bearing, the gears for driving the accessory drive shaft, and the camshaft vertical drive shaft. The rear crankcase section carries the drive gears for the accessories.

Crankshaft.—The crankshaft is a six-throw, seven-bearing shaft, which is statically and dynamically balanced to extremely close limits. The main journals and crankpins are hollow and fitted with oil plugs, which act as

centrifugal oil cleaners and also as oil transfers from main journals to crankpins. The crank cheeks are drilled for two-way feeding of oil from the main journals to the crankpins. The rear end of the shaft carries a standard

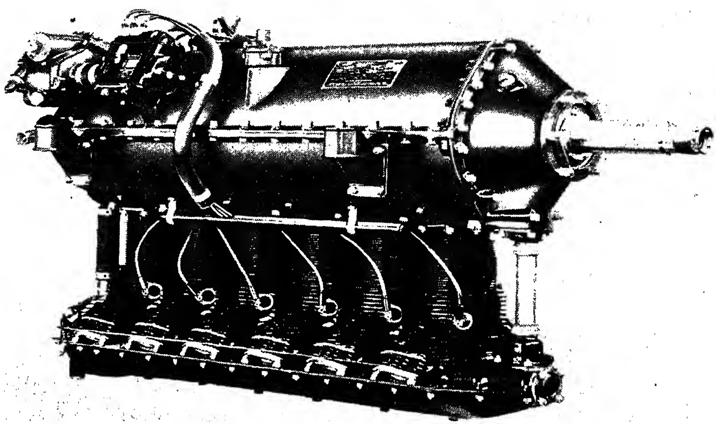


FIG. 2.—Right side of Ranger engine.

starter jaw; the front end has a standard No. 20 S.A.E. spline for the propeller hub. A pendulum-type vibration damper is located on the rear throw of the crankshaft. Figures 4 and 5 show oiling system.

Connecting Rods.—Connecting rods are of I section, machined from chrome molybdenum steel forgings. Steel-backed cadmium-silver bearing shells are used for the main connecting rod bearings, with bronze bushings in the piston-pin end of the rods.

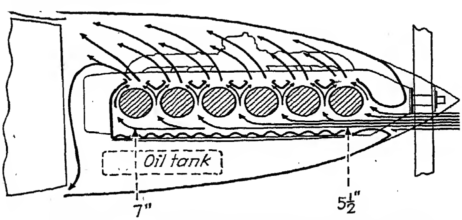


FIG. 3.—Baffles to direct air flow around cylinders for cooling. Figures show inches of water pressure.

Pistons.—The pistons are aluminum alloy, ribbed for strength and cooling. Three $\frac{3}{32}$-in. compression rings are fitted between the piston pin and piston head, with one oil scraper ring at the bottom of the skirt. The piston pins are of heat-treated alloy steel, hardened and ground; they are full floating and are retained by the snap rings in the pistons.

Cylinders.—The cylinder heads are cast aluminum alloy with integral fins, have machined hemispherical combustion chambers, and are screwed and shrunk on the barrels. Aluminum bronze valve seats, one intake and

one exhaust per cylinder, are shrunk into the heads and two spark-plug inserts are shrunk and screwed in and pinned.

The cylinder barrels are machined from chrome molybdenum steel forgings and have integral fins. The skirts project into the crankcase and each barrel is secured to the lower half of the crankcase by eight hold-down studs.

Cylinder Baffles.—Pressure-type cylinder baffles are standard equipment. Pressure baffling forces high-velocity cooling air through and over the finning

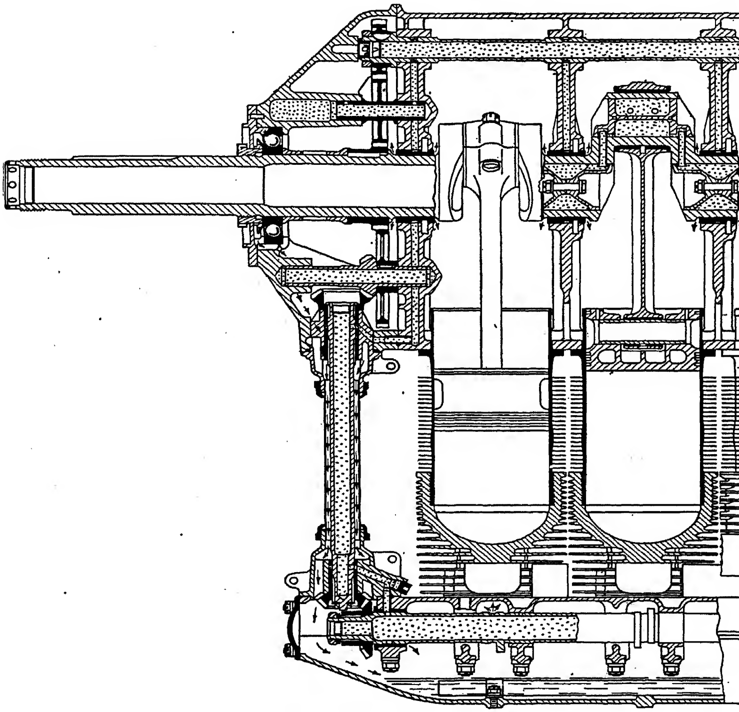


FIG. 4.—Partial section shows oiling system.

on the cylinders. The speed of the plane builds up a positive pressure on the air intake side of the cylinders and a negative pressure on the air outlet side of the cylinders (see Fig. 3).

Valve Mechanism.—The camshaft is a heat-treated alloy steel forging, carried in a housing that bolts directly to the cylinder heads. Housing and cover are of magnesium alloy. The camshaft is supported on eight bearings, one located at each end of the shaft and one adjacent to each of six pairs of cams. It is driven from a vertical shaft, from the front end of the crankshaft. The valves are operated by rocker arms, which are provided

with crowned roller cam followers and ball-type adjusting screws. The end of the adjusting screw is cupped and fitted with a steel ball, which has a flat face to provide a large contact with the valve stem. Pressure oil is fed directly to the camshaft bearings from the hollow camshaft. Holes drilled in the camshaft between each pair of cams supply a spray of oil to rocker arms, cam followers, and adjusting screw (see Fig. 6).

Accessory Drive Shaft.—The accessory drives are protected from crankshaft torsional vibration and shock loading by a long, hollow, flexible shaft, located in the top of the crankcase upper section. This shaft transmits the drive from the propeller end of the engine to the accessory drives in the rear section and completely isolates them from any detrimental vibrations. The accessory drive shaft is carried in seven main bearings in the crankcase webs and acts as a header for distribution of oil to main bearings and front end of engine.

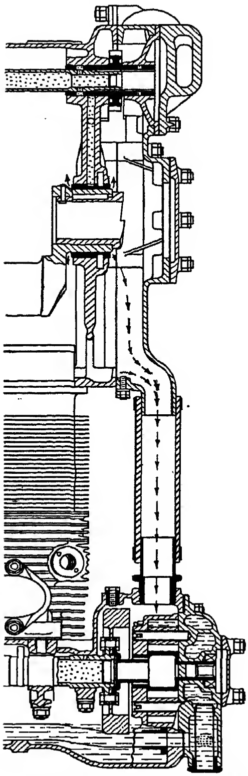


FIG. 5.—More of the oiling system.

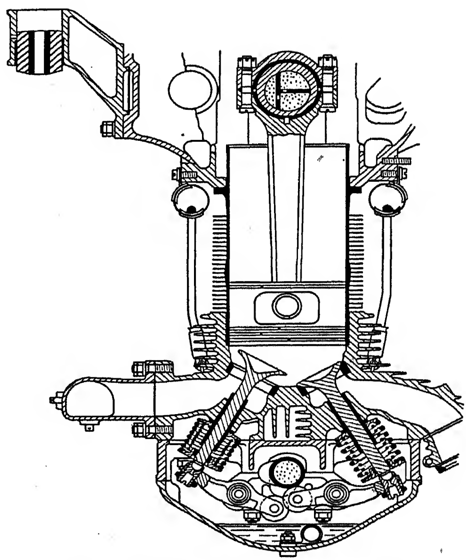


FIG. 6.—Cross section showing valve action.

Lubrication.—The lubrication system is of the full-pressure type. A pressure pump with screens located on the crankcase rear section circulates oil through hollow engine shafts and cast-in passages, there being no external

pressure oil pipes. Part of the oil from the pump is fed to the accessory drives in the rear section, the main supply entering the accessory shaft, which distributes it to the crankshaft bearings and connecting rods. From the front end of this shaft, oil is carried to all drives in the front section and into the camshaft vertical drive shaft. Then the oil flows into the camshaft, which distributes it to the camshaft bearings under pressure, and to the rocker arms and valve stems by spray from holes drilled in the camshaft. The cylinder walls and piston pins are lubricated by oil thrown from the main and connecting rod bearings (see Figs. 4 and 5).

Return oil drains from the crankcase to the camshaft housing through the housing for the camshaft vertical drive shaft at the front, and through the drain pipe at the rear of the engine. All oil, after performing its lubrication function, collects in the camshaft housing. A double scavenge pump located at the rear of the camshaft housing is arranged to take oil from either end of the housing and return it to the supply tank, first passing it through two finger strainers.

Carburetion.—An updraft carburetor is supported on a hot spot, which is bolted to the crankcase on the left side between cylinders 3 and 4. The hot spot connects the carburetor with two pipes leading to the two cast magnesium manifolds, each supplying three cylinders.

Ignition.—Two Bendix-Scintilla magnetos, mounted on the upper crankcase in the rear furnish ignition: *the right magneto, type* SB6R-8, *supplies ignition to the exhaust spark plugs; the left magneto, type* SB6R-10, *supplies ignition to the intake spark plugs.* In starting, the impulse coupling retards the spark on the left magneto until the piston is 8 deg. beyond top dead center. A loaded spring in the coupling then rotates this magneto at high speed, producing a hotter spark than normally could be obtained. As soon as the engine has started, the impulse coupling automatically disengages and the magneto is driven directly.

Accessory Drives.—Drives are provided for the following accessories: starter, generator, fuel pump, vacuum pump, and tachometers. Accessory mounting pads are located on the rear section of the engine.

Cooling a line engine with air involves the careful direction of air flow around the cylinders, by means of properly designed baffles. These were shown in Fig. 3, the arrows indicating the air-flow paths. The figures 5½ and 7 show the pressure at these points in inches of water, indicating greater air pressure at the last cylinder. The temperatures are given in the following table, which may well serve as a guide in testing engine installations. Figures 4 and 5 give two views of the engine.

Cylinder Temperatures*
(Level flight)

Cylinder number	Front 6	5	4	3	2	Rear 1
Head	366	365	355	360	370	350
Base	210	190	200	205	215	215

* Degrees Fahrenheit. Ground air, 63°F.

The Ranger is built in four horsepowers. The cylinders and r.p.m. are the same in all, the different powers being secured by varying the compression ratio. Detailed specifications follow.

Table 1.—Engine Specifications

Model	6-440C-2	6-440C-3	6-440C-4	6-440C-5
Number of cylinders	6	6	6	6
Bore	4.125	4.125	4.125	4.125
Stroke	5.5	5.5	5.5	5.5
Piston displacement, cu. in.	441	441	441	441
Compression ratio	6 to 1	6.2 to 1	6.8 to 1	7.5 to 1
Rated speed, r.p.m. (at sea level)	2,450	2,450	2,450	2,450
Rated brake horsepower (at sea level)	175	180	190	200
Altitude rating	None	None	None	None
Crankshaft rotation	R.H. tractor	Same	Same	Same
Propeller shaft spline size	No. 20 S.A.E.	No. 20 S.A.E.	No. 20 S.A.E.	No. 20 S.A.E.
Vibration dampers	No	Yes	Yes	Yes
Over-all dimensions of complete engine:				
Length, in.	52.906	52.906	52.906	52.906
Width, in.	20.156	20.156	20.156	20.156
Height, in.	30.968	30.968	30.968	30.968
Number of mounting bolts	4	4	4	4
Transverse spacing of mounting bolts; in.	17.625	17.625	17.625	17.625
Position of center of gravity:				
Distance forward of center line of rear mounting bolts, in.	16.187	16.187	16.187	16.187
Distance below center line of crankshaft, in.	6.000	6.000	6.000	6.000
Ignition				
Magneto type:				
R.H.	SB6R-8	SB6R-8	SB6R-8	SB6R-8
L.H.	SB6R-10	SB6R-10	SB6R-10	SB6R-10
Direction of rotation of magneto drive, viewing antipropeller end of engine (both magnetos)	Clockwise	Clockwise	Clockwise	Clockwise
Magneto speed in multiples of crankshaft speed	1.5	1.5	1.5	1.5
Spark occurs, deg. B.T.C.:				
Right magneto	22	25	25	25
Left magneto	22	25	25	25
Spark plugs	B.G.	B.G.	B.G.	B.G.
Valves and timing				
Intake opens, deg. B.T.C.	15	15	15	15
Intake closes, deg. A.B.C.	65	65	65	65
Exhaust opens, deg. B.B.C.	70	70	70	70
Exhaust closes, deg. A.T.C.	30	30	30	30
Intake remains open, crankshaft deg.	260	260	260	260
Exhaust remains open, crankshaft deg.	280	280	280	280
Valve lift, in.	0.500	0.500	0.500	0.500
Valve rocker clearance, both valves cold:				
Timing, intake, deg.	15	15	15	15
Exhaust, deg.	15	15	15	15
Running, intake, deg.	15	15	15	15
Exhaust, deg.	30	30	30	30
Fuel System				
Carburetor type	NA-R4B	NA-R4B	NA-R4B	NA-R4B
Grade of fuel (Ranger spec.) No. 1001, 1002, 1003	65 oct.	73 oct.	80 oct.	87 oct.
Lubrication System				
Grade of oil (Ranger spec.) No. 1005:				
Summer grade, sec	120	120	120	120
Winter grade, sec	100	100	100	100
Oil flow, lb. per min	25	25	25	25
Heat to oil, b.t.u. per min	375	375	375	375
Minimum safe quantity of oil in engine, gal.	1	1	1	1
(Add to this, quantity for oil cooler and tank)				
Speed of pressure oil pump in multiples of crankshaft speed	1.5	1.5	1.5	1.5

Table 1.—Engine Specifications (*Continued*)

Model	6-440C-2	6-440C-3	6-440C-4	6-440C-5
Oil inlet connection (pipe thread), in.	3/4	3/4	3/4	3/4
Oil outlet connection (pipe thread), in.	3/4	3/4	3/4	3/4
Instrument Connections and Accessory Drives				
Oil temperature (thread)	5/8–18	5/8–18	5/8–18	5/8–18
Oil pressure (pipe thread), in.	1/8	1/8	1/8	1/8
Oil tank vent (pipe thread), in.	1/2	1/2	1/2	1/2
Fuel pump drive:				
Shaft size (gear tooth spline)	24/48 Pitch—0.4583 P.D.			
Speed, times crankshaft	0.5	0.5	0.5	0.5
Rotation, viewing drive	Clockwise	Clockwise	Clockwise	Clockwise
Starter drive flange diameter, in.	5	5	5	5
Speed, times crankshaft	1	1	1	1
Rotation, viewing drive	Clockwise	Clockwise	Clockwise	Clockwise
Generator drive:				
Shaft type	S.A.E. spline	Same	Same	Same
Speed, times crankshaft	1.5	1.5	1.5	1.5
Rotation, viewing drive	Clockwise	Clockwise	Clockwise	Clockwise
Flange studs	4	4	4	4
Tachometer drive:				
Thread connection	7/8–18	7/8–18	7/8–18	7/8–18
Speed, times crankshaft	0.5	0.5	0.5	0.5
Rotation, viewing drive	Clockwise	Clockwise	Clockwise	Clockwise
Vacuum pump drive:				
Shaft type	Slotted	Slotted	Slotted	Slotted
Speed, times crankshaft	1.5	1.5	1.5	1.5
Rotation, viewing drive	Clockwise	Clockwise	Clockwise	Clockwise
Weight, dry, including standard equipment*	370	370	370	370

* Standard equipment included in dry weight: two Bendix-Scintilla magnetos plain ignition wires, spark plugs, Stromberg carburetor, pressure oil pump, scavenge oil pump, mounting brackets, exhaust flanges, hot-spot flanges, baffles, accessory drive covers, and primer system.

INSTALLATION IN THE AIRPLANE

Each airplane presents individual engine installation problems. Specific design problems should be submitted to the Ranger Aircraft for consideration.

Unpacking and Cleaning.—Ranger engines are shipped from the factory in sealed packing cases. When required for installation:

Break the seals.

The upper part of the shipping box is merely a cover and is held to the lower part by eight 7/16 bolts. The cover may be lifted off after removing these bolts. Care must be taken to lift the cover straight up so that it will not come in contact with any part of the engine.

Remove the four 5/8 bolts holding the rails to the shipping box. Attach the lifting eye to the propeller shaft. Attach the sling, in the front, to the propeller shaft lifting eye and, in the rear, to the lifting eye on the generator cover.

Lift the engine from the box and remove the two shipping box mounting rails by taking out the four 3/8 attaching bolts.

Wash the packing grease off the engine.

Remove the plugs from the spark-plug holes and tip the engine while turning the crankshaft several revolutions to remove excess oil from the cylinders.

Install the spark plugs.

The engine is now ready for installation. If, after installation, the plane is out of service for any appreciable length of time, the engine should be run

periodically at part throttle to ensure keeping the interior parts slushed with oil. If preferred, the cylinder walls may be sprayed with oil through the spark-plug holes while the engine is being turned over by hand, the spark plugs being afterward replaced. If the engine is to be stored, the cylinders should be sprayed as above and external unpainted parts coated with slushing compound.

Engine Mount.—The engine mount must consider the location of accessories such as drain plugs and connections that must be accessible. The mount should be designed to permit the removal of accessories, such as oil pumps, oil strainers, magnetos, spark plugs, vacuum pump, fuel pump, and carburetor without removing the engine.

Taking into consideration all the factors involved, it is believed that the tubular engine mount structure is the most satisfactory type developed up to this time. In the design of such a mount, it is desirable that the arrangement of members be such as to produce direct stresses only, either tension or compression, without bending.

The engine mounting brackets are designed to accommodate rubber mounting bushings. Owing to the difference in vibration frequencies of various engine mounts, it is desirable to select the proper type of rubber bushings for the mount in which these engines are to be installed.

Cowling.—The design of the cowling depends upon the design of the plane, its performance characteristics, and type of service. It is absolutely essential to maintain a good flow of air around the cylinders and through the engine compartment. The area of the opening at the front of the air scoop should be about 80 sq. in. The cooling air should be drawn out through exit gills at the fire wall. The area of these gills should be approximately 125 to 150 per cent of the inlet area at the entrance to the cooling air scoop. In general, the design of the exit gills should be such as to produce zero static pressure in the engine compartment when operating at full throttle and at the indicated air speed for best climb. The optimum values for satisfactory cooling with minimum drag must be determined through actual flight testing of the particular installation.

When designing the cowling and making the installation, it must be kept in mind at all times that the cylinder cooling is accomplished by building up in the air scoop sufficient pressure to ensure a proper flow of air, and that this air flow is directed by the intercylinder baffles that fit tightly around the cylinder fins. Any leaks in the air scoop will lower the air pressure and reduce the rate of air flow around the cylinders; loose-fitting baffles not only decrease the scoop pressure, but also reduce the volume of air that actually comes in contact with the cooling fins.

The air inlet must be so designed that all air entering the inlet will be directed into the scoop; the scoop must fit tightly at all points of contact with the engine. Baffles or filter plates should have no openings that cannot be tightly closed. Intercylinder baffles must fit tightly around the cylinders, making firm contact with the cooling fins.

Experience indicates that careful flight tests must be made to determine the proper cowling design. The builders will be glad to advise anyone who contemplates designing cowling for Ranger engine installations.

Exhaust.—If a tail pipe is to be used, it should be 3¾ in. in diameter.

Fire hazard, due to blowing of red-hot scale from the exhaust, may be eliminated by using stainless steel or similar heat-corrosion resisting material. Noncorroding material, furthermore, greatly adds to the life of exhaust stacks and collectors.

Tail pipes must not pass under points where fuel or oil may drop on them.

Oil Cooling.—It will be necessary to provide an oil cooler in all Ranger installations. The amount of cooling required varies considerably. During low-temperature operations, it may be necessary to reduce the air flow over the oil cooler to maintain satisfactory oil temperatures. It is advisable to experiment with a new type of installation, to determine the most satisfactory oil cooling system. A 5-in. United Aircraft Products cooler is recommended for the initial testing.

For protection against excessive pressure during cold-weather starting, a relief valve *must* be provided in a by-pass line around the cooler, or incorporated in the cooler. It should open at about 25 lb. per sq. in. pressure.

Oil Tank.—The capacity and type of tank should be decided by the designer. In general, oil capacity should be not less than 1 gal. for each 11 gal. of fuel capacity.

To prevent foaming, the return oil should be discharged below the oil level by running the return pipe to a low point after entering the tank. A small hole should be drilled in the upper wall of the pipe, just after entering, to act as a siphon breaker.

The tank should be located to the rear of the engine and as high as permissible. The oil level should, if possible, be above the oil pump inlet with the plane on the ground and tail down. If this is impossible, the supply line should be carried from the bottom of the tank to a point somewhat above the pump and then led to the pump. The high point in the line should be above the pump when the plane is on the ground with tail down, thus assuring a priming head of oil on the pump when starting the engine.

A vent pipe should be installed from the top of the oil tank to the vent connection in the top of the crankcase rear section, to allow oil vapor within the tank to escape.

The supply and return lines should be at least ¾ in. I.D.

Fuel and Oil Lines.—If copper tubing is employed: Use only finest quality, soft, seamless, hot-drawn copper tubing. Use union connections on all lines except as noted below. Avoid the use of hose connections, *except on the ends of lines that are subject to vibration.* Bead the tubing a short distance from the ends to provide a good grip, and make the ends of the tubing square, assembling them close together inside the hose. Anneal the tubing before and after bending; if the bends are severe, it is advisable to anneal during bending. All lines should be well braced to reduce vibration.

If metallic hose is used: Provide a large area of contact, to make a tight joint when sweating on the fittings at the end of the lines. Use only silver solder. Do not twist the hose in tightening connections. Brace all lines against sagging or chafing.

Fuel System.—If no fuel pump is used, the carburetor will be modified by the factory, at no charge, for gravity feed. This change is essential for satisfactory operation. The gas tank should give a head of at least 35 in. when the plane is inclined at the angle of its steepest climb, the head being measured from the tank outlet. If a fuel pump is used, a pressure of 3 lb. per sq. in., plus or minus ½ lb., must be available at the carburetor.

The fuel pump discharge, or "fuel-out" connection, connects to the carburetor; the "fuel-in" connection, to the fuel supply tank.

A drain from the carburetor air scoop is required and should be led outside the fuselage.

The suction side of the primer should be connected into the fuel line through a reducing tee; the delivery side, to the manifolds at the points indicated on the installation drawing.

Control Connections.—Engine control connections are indicated on the installation drawing. In making such connections, care should be exercised to avoid excessive play.

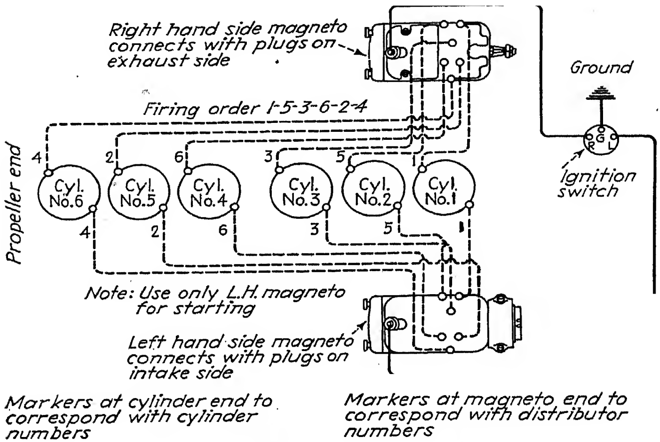


Fig. 7.—Wiring diagram of Ranger engine

Magneto Wiring.—For wiring arrangement refer to the wiring diagram, Fig. 7; use ignition cable for all connections. The ground terminal *must* be connected to the engine crankcase.

ENGINE TROUBLES

The best method of "trouble shooting" is first to decide on the possible causes and then eliminate them one by one, starting with the most probable cause.

The most common troubles and their causes are given with the object of reducing wasted time and increasing the reliability of the engine.

Failure of Engine to Start.—*Lack of Fuel at Carburetor or Insufficient Flow.* Check the fuel tanks, fuel supply lines, primer lines, shutoff cocks, and strainers.

Underpriming.—Check for leaking primer line connections or primer pump packing. Also check the fuel supply to the primer and wobble pump.

Overpriming.—If the cylinders become loaded by overpriming, they may be unloaded by cutting the switch and, with the throttle in the full open position, turning the engine in reverse direction a few revolutions with the propeller.

Defective Booster Magneto.—These engines are equipped with Bendix-Scintilla magnetos; the left magneto is equipped with an impulse coupling which provides the starting boost. Proper functioning of the impulse

coupling is indicated by a sharp snapping sound audible when the engine is turned over by swinging the propeller slowly.

Throttle Opening Incorrect.—The throttle should be set to give approximately 800 to 1,000 r.p.m.

Mixture Control.—Check the mixture control lever to ensure its being in the "full rich" position.

Defective Ignition Wiring.—Examine the ignition wiring for wear, breaks, and incorrect connections.

Dirty Spark Plugs.—Check the spark plugs for proper functioning. Clean, and set the gaps to 0.012-in. clearance.

Magneto Breaker Points.—See that the magneto breaker points are clean and check the setting of the breaker assembly.

Incorrect Timing.—Check the valve and ignition timing.

Cold Oil.—With the ignition switch off, turn the engine over by hand. If very stiff, it will be necessary to drain and heat the oil before starting.

Air Leaks.—Check the intake pipes and carburetor gaskets for air leaks. Check the intake pipe packing nuts for tightness. Check the intake manifolds for holes and cracks. Check the intake manifold nuts and gaskets for tightness.

Carburetor Flooding.—Check the carburetor for leaky float or incorrect float level. When using a wobble pump, work slowly, never exceeding a fuel pressure of 4 lb. Check the carburetor needle valve for restricted movement, improper seating, or worn seat.

Low Oil Pressure. *Lack of Priming.*—Check the oil supply. Disconnect the oil suction line and fill the pump with oil.

Leak in Suction Lines.—Inspect the oil suction lines for air leaks and see that all joints are tight.

Dirt in Oil Screen and Strainer.—Remove and clean.

Air Lock.—Remove, clean, and replace the relief valve.

High Oil Inlet Temperature.—Should not exceed 190 deg.

Improper Setting of Relief Valve.—Set to not over 25 lb.

Excessive Bearing Clearances.—Excessive bearing clearances in the engine due to wear will cause a small drop in pressure over a long period of time.

Low Power.—Check the magnetos with the switch to determine a drop in r.p.m. on each individually. A drop of more than 75 r.p.m. generally indicates faulty ignition in one or more of the following sources: poor spark plugs, broken or damaged ignition wires, defective magnetos or connections.

Check the magneto and valve mechanism for operation and timing.

Check the throttle to determine whether the carburetor throttle valve is opening fully.

Check the fuel supply to the carburetor for proper pressure.

Check the fuel lines and strainers for restriction of flow.

Check the carburetor air intake for restrictions or induction of exhaust

Check for ice formation in carburetor venturi.

Check for air leaks at the intake manifold gaskets, carburetor mounting flange gasket, or carburetor body gasket.

Leaking intake or exhaust valves. With ignition switch off, rotate the propeller shaft to check compression.

Check the propeller for correct design and setting.

Uneven Running.—Check the spark plugs.

Check the magneto timing and operation. Check the ignition harness for broken wires, poor connections, or damaged insulation.

Check the valve mechanism operation and timing.

Check the propeller by installing a propeller from another engine which is known to run smoothly.

Check the propeller hub nut, being certain that it is tight.

Check the propeller for balance and track.

Check the thrust nut to be certain that it is tight.

Check the propeller hub rear cone for galling.

Check the engine mounting bolts for tightness.

Check the engine mount for cracked or broken members.

Check the carburetor setting and operation to be sure that it is functioning properly.

High Oil Temperature.—Check the oil cooling system, particularly the installations that have oil coolers with by-pass valves.

Check the magneto timing.

Check the valve timing and adjustment.

Check the carburetor for lean mixture.

Check the cowling and intercylinder baffles, being certain that they are tight against the cylinders and not interfering with correct air flow over the engine.

Check the quantity of oil in the tank.

INSPECTION

In order to obtain maximum reliability and service from engines, a regular schedule of inspections and overhauls should be maintained. Serious failures often arise from minor causes which could have been prevented by a few minutes' inspection. The recommended inspection schedule is as follows:

Daily Inspection.—See that the ignition terminals and ignition ground wires are secure.

See that the throttle and mixture controls move freely throughout their entire range and that the connections are tight and saftied.

Examine the engine exterior carefully from loose nuts, loose fuel and oil connections, or other abnormal conditions.

Make certain that the fuel and oil supplies are sufficient.

Check the ground r.p.m., remembering that it will vary somewhat with atmospheric changes and wind direction.

See that both magnetos are functioning properly. The drop in speed when operating on either magneto alone should not exceed 75 r.p.m.

Check the oil pressure, oil temperature, and fuel pressure.

See that all cylinder baffles are secure and that there are no leaks in the air scoop.

Fifty-hour Inspection.—In addition to the daily inspection, the following items should be checked every 50 hr., unless otherwise specified.

Compression.—Check the compression of each cylinder, removing the exhaust spark plug from each cylinder, except the one being checked. This should be done while the engine is still warm. This item may be omitted on alternate inspection periods.

Valve Gear.—Valve operating mechanism will run for long periods without adjustment. Unless faulty operation of the engine appears to be caused by an abnormal condition of the valve mechanism, it will be unnecessary to inspect or adjust the valves between overhauls.

Ignition.—Check the spark plugs for fouling and proper gap (0.012). Do not disassemble them unless absolutely necessary. Check the center elec-

Table 2.—Permissible Wear of Engine Parts

Description of limit	Manufacturing min., in.	Manufacturing max., in.	Replacement max., in.
Upper front idler gear and bearing in crankcases:			
Diameter	0.001L*	0.003L*	0.006L
Side clearance	0.001L	0.013L	0.020L
Accessory drive shaft and thrust plug, diam	0.0005L	0.0025T	
Accessory drive shaft thrust plug and front crankcase, clearance	0.008L	0.024L	0.040L
Accessory drive shaft and front drive gear, diam	0.0005L	0.001T	
Accessory drive shaft and bearing in upper crankcase, diam	0.001L	0.003L	0.006L
Accessory drive shaft and rear drive gear:			
Diameter	0.0005L	0.0035L	
Spline side clearance	0.000T	0.004L	
Accessory drive shaft rear gear and bearing in crankcases, diam	0.001L	0.003L	0.006L
Accessory drive shaft rear gear and crankcases, side clearance	0.003L	0.031L	0.040L
Generator adapter and rear crankcase, pilot diam	0.000T	0.003L	
Rear idler gear and bearings in crankcase:			
Diameter	0.001L	0.003L	0.006L
Side clearance	0.004L	0.028L	0.040L
Magneto drive gear and bearings in crankcases:			
Diameter	0.001L	0.003L	0.006L
Side clearance	0.004L	0.028L	0.040L
Magneto drive gear and magneto drive coupling, diam	0.000T	0.002L	
Magneto drive gear oil retainer and crankcase, diam	0.001T	0.005T	
Magneto drive gear and pressure oil pump drive shaft, spline side clearance	0.005L	0.009L	
Pressure oil pump drive shaft and cover, diam	0.001L	0.003L	0.006L
Pressure oil pump drive shaft and housing, diam	0.0005L	0.002L	0.006L
Pressure oil pump drive shaft and drive gear, diam	0.000T	0.0015L	
Pressure oil pump driven gear shaft and housing, diam	0.001L	0.003L	
Pressure oil pump driven gear shaft and driven gear, diam.	0.0005L	0.0025L	0.006L
Pressure oil pump gears and housing:			
Side clearance	0.001L	0.007L	0.010L
Diametral clearance	0.003L	0.007L	0.010L
Pressure oil pump gears, total permissible backlash in finished pump		0.010	0.025
Pressure oil pump cover and rear crankcase, pilot diam.	0.001L	0.003L	
Oil pressure relief valve spring pressure at 0.500 in. height (wire diam. 0.071 in.)	9.5 lb.	10.5 lb.	
Vacuum pump drive gear oil retainer and housing, diam.	0.0005T	0.0035T	
Tachometer drive idler gear and bushing, diam. (press fit)	0.0005T	0.002T	
Tachometer drive idler gear bushing and shaft, diam	0.001L	0.0025L	0.006L
Tachometer drive idler gear and housing, side clearance	0.001L	0.009L	
Tachometer drive idler gear shaft and rear crankcase, diam	0.0005L	0.001T	
Tachometer drive idler gear shaft and housing, diam	0.0015L	0.003L	
Tachometer gear and insert, diam	0.0015T	0.0045T	
Tachometer gear and adapter, diam	0.001L	0.003L	0.006L
Tachometer gear and housing, end clearance	0.002L	0.020L	
Tachometer gear adapter and housing, diam	0.0005L	0.001T	
Thrust bearing nut, tightening torque	500–600 in.-lb		
Thrust bearing nut and front cover, diam	0.011L	0.026L	
Thrust bearing front cover and front crankcase, pilot diam	0.0009L	0.0039L	
Thrust bearing and front crankcase:			
Diameter	0.0002L	0.002L	
Clamp	0.0003T	0.0093T	
Thrust bearing and crankcase, diam	0.0001L	0.0012L	
Crankshaft and crankshaft gear, diam	0.0006L	0.0021L	
Crankshaft gear and key:			
Clearance in shaft	0.0005L	0.0015T	
Side clearance in gear	0.000T	0.002L	
Top clearance in gear	0.0026L	0.0141L	
Crankshaft and oil plugs, diam	0.0005T	0.0025L	

* The letters L and T mean "loose" and "tight" by the amount shown.

Table 2.—Permissible Wear of Engine Parts (*Continued*)

Description of limit	Manufacturing min., in.	Manufacturing max., in.	Replacement max., in.
Crankshaft and hollow dowel, diam.	0.001L	0.005L	
Crankshaft and starter jaw, diam.	0.000T	0.0015T	
Crankshaft and starter jaw and key:			
Side clearance in shaft	0.000T	0.002L	
Side clearance in jaw	0.0005L	0.0015T	
Top clearance in jaw	0.0055L	0.0165L	
Main bearing and crankcase:			
Projection of bearing shell beyond center line of 2.9375 diam. block at 700 lb. pressure	0.001	0.0015	
Equivalent diametral crush in crankcase	0.0013	0.0029	
Main bearing and crankshaft when assembled in crankcase diam.:			
Vertical axis	0.0017L	0.0042L	0.007
Horizontal axis	0.0027L	0.0052L	
Main bearing studs and crankcases, diam.	0.002L	0.004L	
Main bearing hold-down nut, tightening torque	420–480 in.-lb.		
Connecting rod bearing and crankpin:			
Diam.	0.002L	0.004L	0.007L
Side clearance	0.0065L	0.0165L	
Connecting rod bearing and connecting rod:			
Projection of bearing shell beyond center line of 2.406 diam. block at 1,400 lb. pressure	0.0005	0.001	
Equivalent diametral crush in crankcase	0.0006	0.0023	
Connecting rod bearing and connecting rod, side clearance	0.0015T	0.0025L	
Connecting rod and cap and bolt, diam.	0.0005T	0.001L	
Connecting rod bolt, tightening torque	350–400 in.-lb.		
Connecting rod and bushing, diam.	0.002T	0.004T	
Piston pin and bushing, diam.	0.001L	0.0025L	0.006L
Piston pin and piston, diam.	0.000T	0.0015L	0.003L
Piston oil scraper ring, gap	0.020	0.024	0.040
Piston oil scraper ring and groove, side clearance	0.0005L	0.002L	0.0045L
Piston compression ring, gap	0.020	0.024	0.040
Piston compression ring and bottom groove, side clearance	0.002L	0.0035L	0.006L
Piston compression ring and intermediate groove, side clearance	0.005L	0.0065L	0.009L
Piston compression ring and top groove, side clearance	0.006L	0.0075L	0.011L
Piston skirt† (bottom) and cylinder, diam.	0.009L	0.013L	0.023L
Piston skirt† (top) and cylinder, diam.	0.012L	0.016L	0.026L
Piston intermediate land and cylinder, diam.	0.020L	0.024L	0.034L
Piston top land and cylinder, diam.	0.024L	0.028L	0.038L
Cylinder barrel bore:			
Wear			0.010
Out-of-round			0.005
Cylinder barrel and crankcase, pilot diam.	0.006	0.022	
Cylinder hold-down nut, tightening torque	250–300 in.-lb.		
Spark plug, *tightening torque*	*450–500 in.-lb.*		
Valve seat and cylinder head intake and exhaust, diam. (shrink fit)	0.008T	0.012T	
Valve guide and cylinder head:			
Intake, diam. (shrink fit)	0.0015T	0.003T	
Exhaust, diam. (shrink fit)	0.002T	0.0035T	
Intake valve and guide, diam.	0.002L	0.004L	0.009L
Exhaust valve and guide, diam.	0.003L	0.005L	0.010L
Valve spring press:			
Outer (wire diam. 0.168 in.) compressed to 1 11/3		56–62 lb.	
Inner (wire diam. 0.120 in.) compressed to 1 5/16 in.		29–32 lb.	
Valve rocker and needle bearing, diam.	0.001L	0.001T	
Valve rocker needle bearing and shaft, diam.	0.0002L	0.0023L	
Valve rocker shaft and support, diam.	0.000T	0.0015L	
Valve rocker and support, side clearance	0.002L	0.026L	
Valve rocker shaft support and cam housing attachment nut, tightening torque	150–200 in.-lb.		
Valve rocker roller and spacer, diam.	0.0015L	0.003L	0.007
Valve rocker roller and rocker, side clearance	0.0045L	0.0105L	0.015
Valve rocker roller spacer and rivet, diam.	0.000T	0.0025L	

† Piston skirt is cam ground 0.006 eliptical. Limits shown are on major axis of ellipse at center line of thrust face.

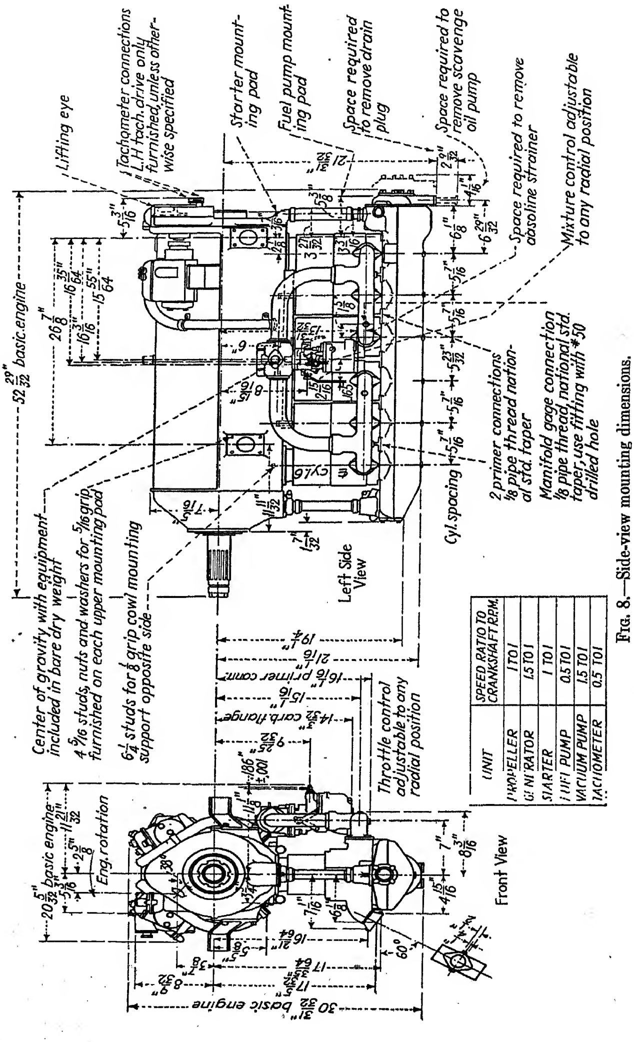
Table 2.—Permissible Wear of Engine Parts (*Continued*)

Description of limit	Manufacturing min., in.	Manufacturing max., in.	Replacement max., in.
Valve rocker roller clearance, when engine is cold:			
For timing:			
Intake	0.015		
Exhaust	0.015		
For running:			
Intake	0.015		
Exhaust	0.030		
Lower front idler bevel gear and bearing in crankcases, diam	0.001L	0.003L	0.006
Lower front idler bevel gear and spur gear, diam	0.0005L	0.002T	
Lower front idler bevel gear and key:			
Side clearance in shaft	0.000T	0.0027T	
Side clearance in gear	0.0005T	0.0025T	
Top clearance in gear	0.0045L	0.016L	
Thrust washer‡ for bevel gears			
Vertical drive shaft upper bevel gear and support, diam	0.001L	0.003L	0.006
Vertical drive shaft upper support and front crankcase, pilot diam	0.000T	0.003L	
Vertical drive shaft and upper bevel gear, diam	0.002L	0.004L	
Vertical drive shaft and upper bevel gear, spline side clearance	0.007L	0.011L	
Vertical drive shaft and lower bevel gear:			
Diameter	0.002L	0.004L	
Spline side clearance	0.007L	0.011L	
Vertical drive shaft lower bevel gear and support, diam	0.001L	0.003L	0.006
Vertical drive shaft lower support and camshaft housing, pilot diam	0.000T	0.002L	
Camshaft and bevel gear:			
Diameter	0.000T	0.002L	
Spline side clearance	0.001L	0.003L	
Camshaft and bushing, diam	0.001L	0.003L	0.006
Camshaft bushing and housing, diam	0.000L	0.0015T	
Camshaft and housing, diam	0.001L	0.003L	0.003
Camshaft and flywheel and scavenger oil pump drive adapter, diam	0.000T	0.002L	
Bolt and camshaft flywheel and scavenger oil pump drive adapter, diam	0.000L	0.0015T	
Scavenger oil pump drive gear and cover, diam	0.001L	0.003L	0.006
Scavenger oil pump drive gear and housing, diam	0.001L	0.003L	0.006
Scavenger oil pump drive gear and adapter, spline side clearance	0.001L	0.003L	
Scavenger oil pump gears and housing:			
Side clearance	0.001L	0.007L	
Diametral clearance	0.003L	0.007L	
Scavenger oil pump drive gear and driven gear, total permissible backlash in finished pump		0.010	0.025
Scavenger oil pump driven gear and shaft, diam	0.0005L	0.0025L	
Scavenger oil pump driven gear shaft and housing diam	0.0005L	0.0025L	
Scavenger oil pump housing and oil retainer	0.001T	0.007T	
Scavenger oil pump housing and camshaft housing and cover, pilot diam	0.000T	0.003L	
Mounting bracket and main crankcase, pilot diam	0.001L	0.005L	
Mounting bracket and bushing, diam	0.0015T	0.0035T	
Front crankcase and main crankcase, pilot diam	0.001T	0.003L	

‡ Grind thrust washers as required to align cone centers of mating bevel gears.
Woodruff key and keyways conform with S.A.E. specifications.
Backlash on all gears not otherwise shown 0.001–0.007 in.; replace at 0.025 in. backlash.
All dowel pins have the following limits unless otherwise specified:

Tight end	0.0005T min.	0.0025T max.
Loose end	0.000T min.	0.002L max.

All stake pins must be of a good drive fit.
Replace circlet-type piston pin retainer at each overhaul.
Replace piston rings at each overhaul.



UNIT	SPEED RATIO TO CRANKSHAFT R.P.M.
PROPELLER	1 TO 1
GENERATOR	1.5 TO 1
STARTER	1 TO 1
FUEL PUMP	0.5 TO 1
VACUUM PUMP	1.5 TO 1
TACHOMETER	0.5 TO 1

FIG. 8.—Side-view mounting dimensions.

trode for tightness. Reset the gaps when necessary. When testing bomb, the plug should fire regularly with 125-lb. pressure.

Remove the scavenge oil pump plugs and screens for inspection and cleaning.

Clean the oil cooler.

Remove the pressure oil screens and filters for inspection and cleaning.

Inspect all oil lines and connections for leaks and tightness and chafing.

Lubrication.—Drain the camshaft housings and oil tank and fill the tank with fresh oil.

Remove and clean the scavenge pump strainers.

Clean the oil cooler.

Inspect all oil lines and fastenings.

Remove engine oil strainer and clean the entire assembly.

Fuel and Induction System.—Remove the carburetor fuel strainer and clean.

Clean the fuel tank sediment bulb.

Check the fuel lines and connections for tightness and leaks.

Check the carburetor air scoop for tightness.

Check the intake pipe packing nuts for tightness.

Exhaust System.—Check the exhaust pipes, exhaust manifold, and tail pipes for tightness and cracks.

Check for excessive heat and resulting corrosion.

Miscellaneous.—Check the following for tightness.

Accessory flange nuts.
Cylinder flange nuts (every 100 hr.).
Propeller hub on crankshaft.
Thrust bearing nut.
Engine mounting bolts.
Exhaust flange stud nuts.

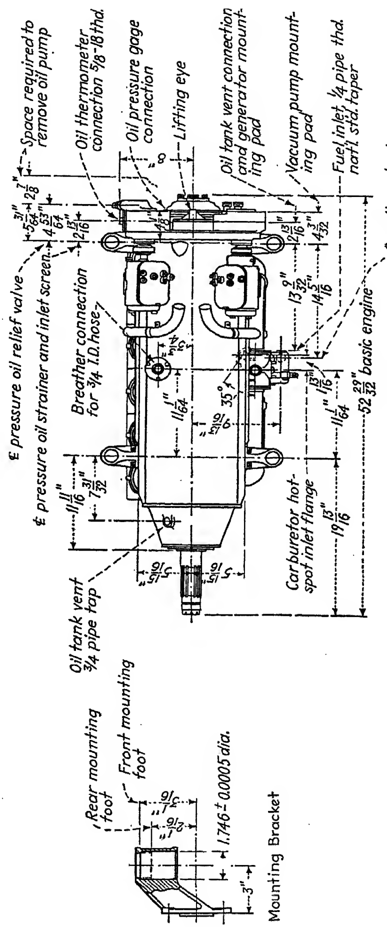


FIG. 9.—Top mounting dimensions.

When Ranger engines are torn down for overhaul or inspection, the wear of parts should be checked by the table on page 253. The first two columns give the manufacturing tolerances and the last the point at which the part should be replaced.

Engine in Section.—Figures 4 and 5 show the Ranger engine in section. Table 2 shows the name of each part and gives the wear limits.

The wiring diagram for the magneto ignition circuits (Fig. 7) will also be found extremely useful. Mounting dimensions and other interesting details are seen in Figs. 8 and 9.

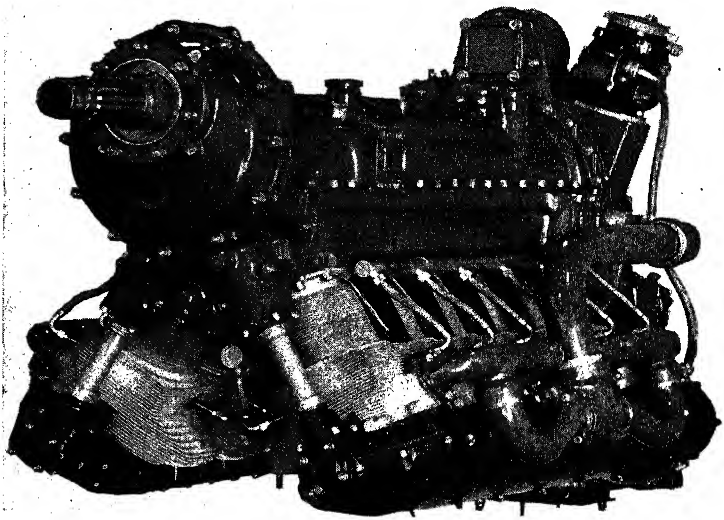


FIG. 10.—New 12-cylinder Ranger engine.

Another series of Ranger engines are now being built. They are 12-cylinder, inverted, 60-deg. V engines, with a maximum of 520 hp. at 3,100 r.p.m. for take-off and up to 8,000 ft. At a recommended cruising speed of 2,500 r.p.m., the horsepower is rated at 300 at 13,000 ft. altitude. This engine is shown in Fig. 10.

SECTION VIII

KINNER, LAMBERT, AND WARNER ENGINES

KINNER ENGINES

Kinner engines are of the four-cycle radial, air-cooled type, built by Kinner Motors Inc., Glendale, Calif. They are five-cylinder engines built in two series. Models B-5 and B-5R are rated at 125 hp. at 1,925 r.p.m. Both of these develop the same power but the B-5R has been improved over the B-5, mainly in the cylinder head equipment. It has a rear exhaust instead of in front as formerly. The new cylinder head can be put on the older engines. Two views of the engine are seen in Figs. 1 and 2. Mounting dimensions are shown in Figs. 3, 4, and 5.

A newer engine, R-5, has 160 hp. at 1,850 r.p.m. The cylinders have 5-in. bore and the stroke 5½ in. giving a displacement of 540 cu. in. The compression ratio is 5.5 to 1. Ignition is the same. The carburetor is Stromberg NA-R6. The weight is 344 lb.; 33 lb. more than the older series. The outside dimensions are the same as shown in Table 1.

Crankcase.—The crankcase has an aluminum-alloy main section with an internally ribbed front cover and a rear cover of the same material.

The main crankcase section contains the cylinder pads, cam drive compartment, a ring type fuel mixture induction manifold, and the engine support studs. A central web carries the rear main bearing and the front bearings of the camshafts and magneto drive shafts. The cam follower guides are placed radially in the rear portion of the main crankcase. The front cover contains a large front main bearing and a ball thrust bearing. Both main bearings are copper-lead, steel backed. The rear cover carries the rear cam gear bearings and supporting flanges for the oil pump, as well as the magneto drive shafts and the two magneto support brackets. A starter adapter, with a standard S.A.E. 5-in. mounting flange, which has a 4-in. bolt circle, can also be mounted on the rear cover.

Crankshaft.—The one-piece crankshaft is forged from chrome-nickel steel, heat treated, and machined all over. It is drilled for lightness and for oiling the piston pin. Outlet holes form oil passages for the main and crankpin bearings. Two counterweights are each held to the crank-cheek extension by three cap screws. The timing pinion is bolted on the rear end of the crankshaft. The propeller end of the crankshaft conforms with S.A.E. standard No. 1 taper.

Connecting Rods and Pins.—The connecting rods consist of a split type master rod and four link rods, of the same material as the crankshaft. Link pins are retained in the master rod by spring catch pins. The piston pins are of the full floating type with aluminum alloy and buttons to prevent scoring the cylinder walls. The master rod bearing is copper-lead, steel backed. Each end of the link rod has a hard bronze plain bearing of ample dimensions.

Pistons.—The pistons are heat-treated, semipermanent mold, aluminum-alloy castings with internal ribs for bracing and cooling. Each piston has three compression rings and one oil control ring.

Cylinder Head and Barrel.—The cylinder head and barrel are two separate units, assembled together with studs and nuts. The barrel is made of heat-treated steel with integral cooling fins. The bore is machined and ground. The head is heat-treated cast aluminum alloy with large cooling fins. Each head contains two overhead valves slightly inclined to cylinder axis and two spark plugs located in the top of the combustion chamber. Valve guides are special bronze alloy pressed into the head. The valve seats are hard aluminum-bronze shrunk into the head. A cover completely encloses the rocker arm mechanism.

Table 1.—General Specifications

Approved type certificate	No. 51
Model	B-5 or B-5R, Series 2
Rated hp	125 C.A.A. rating at 1,925 r.p.m.
Bore	4⅝ in.
Stroke	5¼ in.
Displacement	441 cu. in.
Compression ratio	5.25 to 1
Ignition	2 Bendix-Scintilla magnetos
Carburetor	Stromberg NA-R5A or Holley 419
Crankshaft propeller end	No. 1 S.A.E. standard
Engine weight dry, *without* carburetor air heater, exhaust collector ring, starter drive, fuel pump drive, or propeller hub, but *including* hub nut and starter adapter	311 lb.
Starter adapter weight	8.5 lb.
Fuel pump drive weight	1.3 lb.
Individual stack and heater assembly	10 lb.
Hub for wooden propeller	8.5 lb.
Dimensions	
Over-all diameter	45⅜ in.
Mounting bolt circle	14 in.
Total length	32$\frac{5}{16}$ in.
Mounting dimensions are shown in Fig. 9.	

Valve Mechanism.—Each cylinder head is fitted with noninterchangeable, special steel tulip valves. The valves are closed by double helical springs and are opened by rocker arms, operated by push rods and tappets riding upon individual cams. The rocker arm is supported by a special, heavy-duty, roller bearing. Valve clearance adjustment is made through the rocker arm socket, locked by a lock nut, on the adjusting screw. Push rods are ball ended to fit into the rocker arm screw socket and the cam follower socket. The cam followers (commonly called "tappets") are of the roller type. The camshafts are driven by the timing pinion at the rear end of the crankshaft. The valve timing is built into the engine and requires no adjustment. The timing is obtained by securing the correct location of the timing pinion teeth relative to the tongue fitting in the groove of the crankshaft, and the correct location of the cams relative to the gears of the camshafts, causing thereby the proper relative location of the cam followers, camshafts, and crankshaft. Numbers are stamped on the teeth or tooth spaces of the pinion and cam gears to ensure proper assembly.

Carburetion.—Carburetion is supplied by one Stromberg NA-R5A or Holley model 419 aviation carburetor. The carburetor is equipped with a manually operated altitude control. A special air heater is provided. A cutout valve is inserted in the hot-air connection for operation in cold weather. This heater also permits the installation of an air intake pipe leading from the top or side of the cowling. The air intake, because of its location, draws clean air at all times and reduces the hazard of dust entering the carburetor.

Ignition.—Two Bendix-Scintilla PN-5D or SB-5L magnetos supply ignition through two spark plugs in each cylinder. The PN-5D magneto is used on the early type B-5 engine, having been superseded by the SB-5L.

The right magneto fires the plugs located at the front of the cylinder; the left magneto fires the rear plugs. An ignition wire harness eliminates any loose wires at the rear of the engine. The engine may be mounted without removing or disturbing any wires.

Lubricating System.—The conventional pressure lubrication with dry sump is used. The pump is of the two-unit type. The pressure pump forces oil through the crankshaft from the main bearing to the rear and out by an oil pressure relief valve located on the rear cover. The scavenger pump is entirely separate, eliminating the possibility of air destroying the pump capacity. This pump drains the sump and returns the oil to the supply tank. The two main bearings, the master rod bearings, and the link pin bearings are pressure fed; the remainder of the mechanism is lubricated by splash thrown by the crankshaft.

Installation.—The engine mount should be properly braced and the structure should show no undesirable vibration when the engine is in operation. The engine can be placed in the mounting ring without disturbing any parts or wiring. Ten engine mount studs, protruding 1¾ in. from the engine, are standard equipment. The engine mounting surface should be flush with the mounting ring at all points along the contact surface. Leather or fiber washers may be used between the case and the ring, or mounting ring and supports, to dampen out any vibration. Consult the manufacturers for details regarding rubber mounting. All nuts should be locked or cottered.

Wiring.—The wiring of the engine, as shipped, is complete and should not be disturbed except to connect the two ground wires to the control switch. *Be sure to use the special ground wires furnished with the engine, when PN-5D magnetos are used.* If rubber mounts are used the engine and ignition switch should be grounded to the airplane structure.

Fuel Lines.—For gravity feed, a fuel head of 11 in. (28 cm.) or more should be maintained at the lowest point of fuel tanks, unless otherwise provided for. All fuel connections, between different units in the installation, which might vibrate, should be made with a short length of gasoline-resisting rubber hose, using a connection designed to prevent actual contact of the hose with the fuel in the pipes, that is, hose liners. Approved type flexible lines may be used. Care should be exercised to prevent air locks in the line. The gas lines should be not less than ⅜ in. diameter tubing.

Insert the strainer in the fuel tank or in the line.

The drain from the carburetor air heater should be led outside the cowling. A primer may be used when no starter is installed. Install the three nozzle ells in the intake passages of cylinders 1, 2, and 5, in the holes provided for them. Use only high-grade aviation gasoline having a commercial antiknock rating of 73 octane or better.

Under no circumstances should low-grade gasoline be used for fuel. Its tendency to detonate causes overheating and preignition resulting in excessive wear, loss of power, cracking of cylinder heads, and shortening of the life of the engine.

Carburetor Controls.—The throttle and mixture control should open and close fully and easily, but should have sufficient friction on the levers in the cockpits to prevent any changes of position except when operated by pilot. There should be as little lost motion as possible. The use of brackets and bell cranks is urged if any delivery of motion at large angles is necessary.

A carburetor air heater is supplied with the engine. The heater valve should not be used in the closed position, that is, by allowing all heat to enter the carburetor, as a decided loss of power will result. Carefully adjust the

opening of the valve to maintain approximately between 60°F. (15.6°C.) to 70°F. (21.1°C.) air temperature in the carburetor. No more heat should be used than is necessary to prevent icing.

Propeller.—Extreme care should be exercised in mounting the propeller on the crankshaft. Clean both the shaft and the hole in the hub. Oil all parts with heavy cylinder oil and place the hub on the shaft. The hub when pressed on by hand should have a slight clearance in the small end between the hub and the shaft.

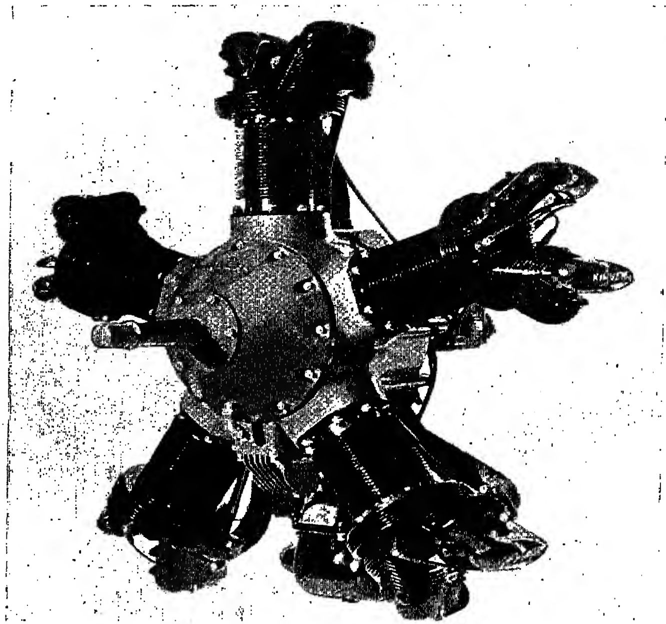


Fig. 1.—Front end of a Kinner 5-cylinder, radial engine.

The contact surface should be not less than 1 in. on the large end of the taper. The amount of contact may be determined by surfacing the interior of the hub with chalk and sizing the propeller hub on the shaft. If the hub contact is only on the small end of the taper, the crankshaft will be severely strained and may break after a few hours' operation. Galling of the large end of the taper may also result if the propeller hub does not fit correctly. In the event a hub does not fit, it should *not* be lapped on the crankshaft but the proper fit should be obtained by remachining the hub to the correct taper.

Tighten the propeller nut securely. Install the propeller hub lock nut, tighten securely, and secure with a spring lock ring.

Be sure that the propeller is tracked and balanced and that all nuts are tight and cottered.

Tachometer.—The tachometer drive connections for S.A.E. standard aircraft ⅞-in. 18-thread couplings are located to the left of the right-hand magneto and to the right of the left-hand magneto. They rotate at one-half crankshaft speed, in reverse crankshaft direction.

Starter.—The B-5R Series 2 engine has a starter adapter with a standard 5-in. starter mounting flange located between the magnetos on the rear

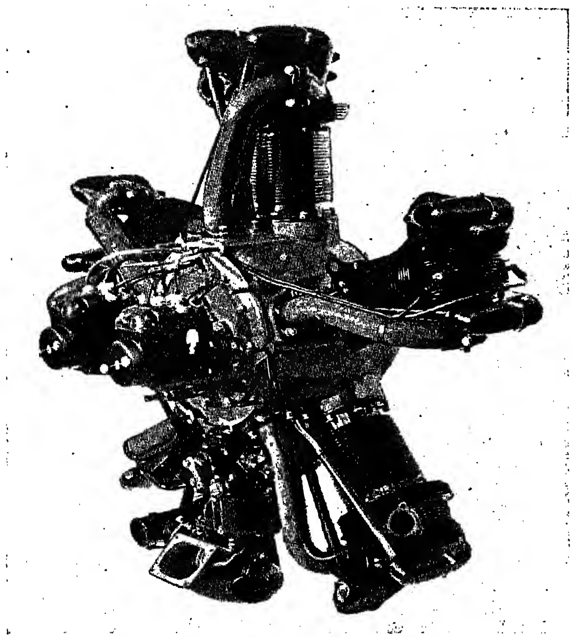


FIG. 2.—Valve-rod end of a Kinner radial engine.

cover. This makes it possible to use any standard type starter now in use which has a 5-in. flange with 4-in. bolt circle.

One of the magnetos is provided with an impulse coupling, which materially helps starting in case a hand turning gear starter is used.

The B-5 engine has provision on the rear cover for a special Eclipse air starter. The complete installation of this starter should not be made until the engine has been mounted in the ship because of the air lines.

Oil Line.—Since it is well known that "plumbing" is the source of many a forced landing, it is essential that great care be observed with this part of the installation. If copper tubing is used, all oil and gas lines should be made of

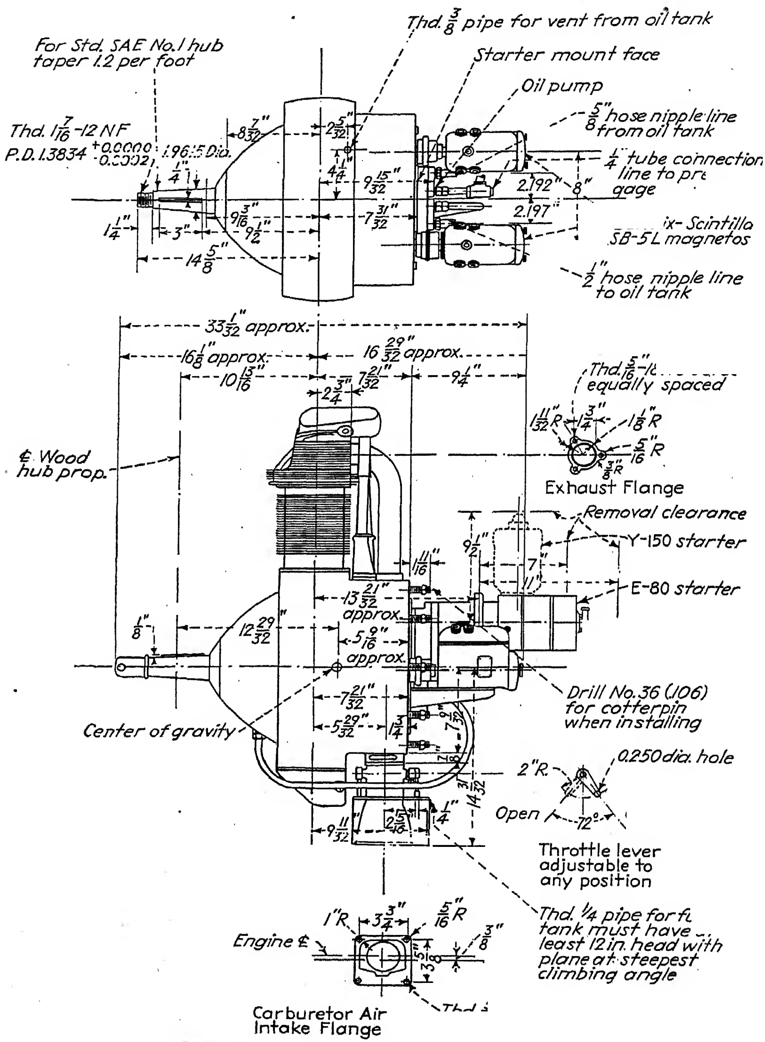
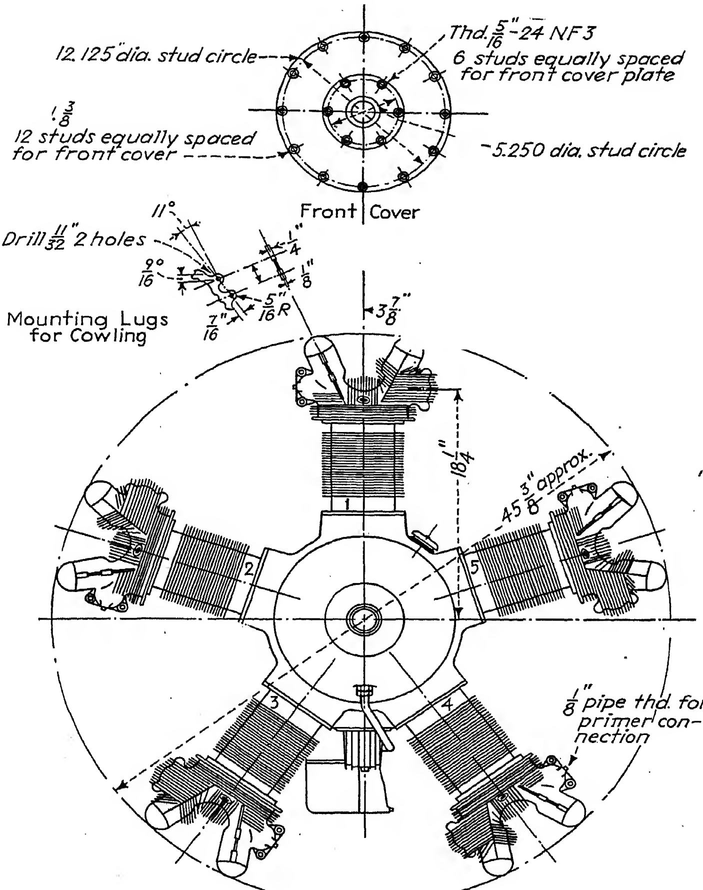


FIG. 3.—Side mounting dimensions and details.



Important note;
If possible install oil tank in such a position that the oil level in the full tank will be the same as the center line of the oil pump with the ship in

should be placed in line from tank to oil pump on engine

FIG. 4.—Front view and connections.

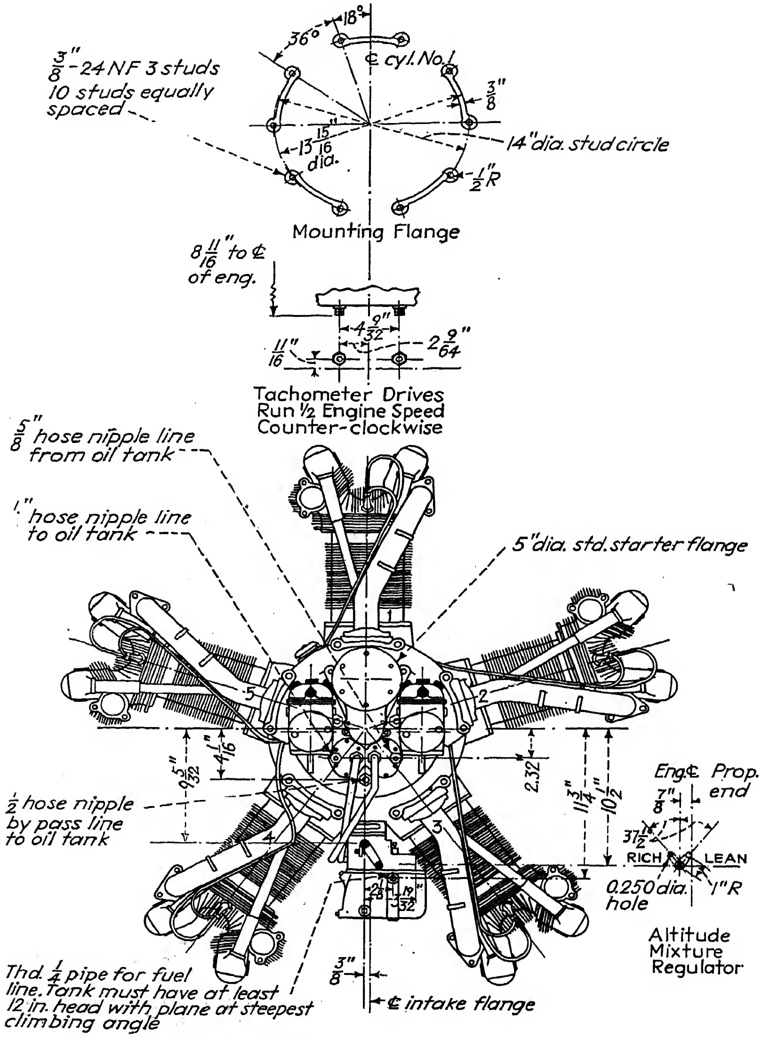


Fig. 5.—Other installation dimensions.

soft seamless hot-drawn tubing of best quality. All tubing must be annealed before and after bending, flaring, or other cold-working operations. Gasoline and oil-resistant hose must be used when hose connections are employed, being sure to use hose liners with rubber hose. Air and gas leaks must be carefully avoided. Lines must be braced to avoid vibration.

The engines are shipped with the necessary oil lines other than the suction line from the tank, the scavenger line from the pump to the tank, the return line from the tank to the regulator, the gage line, and the vent line.

In locating the oil tank, it is desirable to have as short lines as possible. Its capacity should be in accordance with the C.A.A. Civil Air Regulations. Never use an oil tank with less than a 3 gal. capacity. The maximum dimension of the tank should be in the vertical direction.

The oil tank vent may be connected with ½-in. tubing to the connection provided for it on the upper part of the main crankcase of the engine. If possible, install the tank in such a position that the average top level of the oil is the same height as the center line of the pump when the plane is in landing position. The suction line should not be less than ½ in. in diameter and should be as short as possible. All oil connections between different units of the installation, except oil pressure gage lines, should be made with a short length of gasoline-resisting rubber hose, using a connection designed to prevent actual contact of the hose with the oil. Approved type flexible lines may be used.

Refer to the installation drawing (Fig. 5) for proper size of oil lines and locations.

Ordinarily it will not be necessary to install an oil cooler on the Kinner engine. However, a cooler may be necessary with certain types of installation or under unusual weather conditions. It is recommended that the oil lines be lagged in cold weather, but in warmer weather this lagging should be removed.

Engine Troubles.—It is not an easy matter to determine the exact cause of improper engine functioning as it may come from several sources. The best way is to take into account all possible sources to which the trouble may be attributed and to eliminate them in logical order. Following is a list of the most common troubles, for the benefit of the person who is responsible for the proper functioning of the engine. It is urged that this be studied carefully and consulted whenever the occasion warrants, as it will undoubtedly contribute to increasing the reliability and life of the engine.

Analyzing Failure to Start.—If the engine fails to start, it may be due to any one of the following causes:

Lack of fuel. Examine the fuel supply, shutoff cocks, traps, strainers, and hose connections. Make sure there are no air locks in the line.

Under- or overpriming. This occurs very frequently.

Incorrect throttle opening.

Water in carburetor. Remove the strainer and plugs in the accelerating well to drain water.

Cold oil. Turn the engine over by hand with the ignition off; if the engine seems stiff, the oil should be drained and heated before starting the engine.

Dirty spark plugs. Clean the plugs and set the gaps.

Magneto. Test the spark delivered by the magneto; also check the points for proper gap and cleanliness.

Incorrect valve tappet clearance. Check tappet clearance and adjust to the clearance recommended on the data plate on the engine. It should not vary more than 0.002 in.

Incorrect ignition timing. Check carefully all ignition wires for broken places and make sure that all connections are correct and tight. See that the ground wire does not make contact at any place except the switch.

Check the entire system for air leaks.

Check the ignition switch.

Low Power and Rough Operation.—The full-throttle speed will vary as much as 100 r.p.m., under differences in wind, humidity, and other weather conditions, and also condition of propeller (loss of smoothness because of dents, wear of propeller, leading edge, damage to tips, etc.

Low power and roughness of running may be due to

Abnormal fuel-air mixture. Mixture control position, idle adjustment, clogged jets, leaks in induction system, improper spark setting.

Ignition. Dirty spark plugs, broken ignition cable, broken distributors.

Valve gears. Sticking valves, excessive or not enough tappet clearance, broken parts such as springs, tappets, weak valve springs, etc.

Loss of compression. Warped or sticking valves, no oil on pistons, piston rings worn. Warping valves can often be straightened by running the engine up to power and then cooling it gradually by bringing it to idle slowly.

Poor fuel. Fuel knock is generally accompanied by loss of power, after the firing of spark plugs when switched off at full power, burning of pistons, and overheating of engine. With good spark plugs, the addition of 20 to 50 per cent benzol to a poor gasoline shows a marked improvement in power and running conditions. *It is exceedingly important always to use aviation grade gasoline.* Kinner engines are guaranteed only when operated on grades of aviation gasoline which have a commercial antiknock rating of 73 octane or better. It is preferable to use fuels with a higher octane rating than 73 if obtainable, provided the tetraethyl lead content is not in excess of 1½ to 2 cu. cm. per gal. of fuel. The Kinner engine warranty is absolutely void if fuel of a lower commercial octane rating than 73 is used in the engine at any time. (The same is true of other engines.) If fuels are used which contain tetraethyl lead, it is important at the end of flights when the ship is placed in storage for any length of time, to run the engine for not less than 30 min. on clear gasoline to remove all traces of lead. Also clean the valves, valve springs, and valve guides with kerosene to prevent the steel parts from rusting and to prevent sticking valves. Tetraethyl lead in contact with moisture produces a bromic acid, which readily attacks aluminum bronze of which the valve guides and seats are made.

Overheating. This may be caused by lean mixture, which may be the result of improper use of altitude control, preigniting spark plugs, or poor fuel. It is recognized by a dropping off of speed just after being brought up to speed from idling. Considerable damage is liable to occur in operating an engine which is overheated. Other causes of overheating are improper cowling, very high air temperature, low air speed, thin or unsuitable oil, restrictions in exhaust manifolding, or leaks in the intake manifold. It is recommended that a cylinder head temperature gage be installed with a thermocouple washer on the rear spark plug of cylinder 1 to indicate the cylinder head temperatures. The airplane should be flown in such a manner as to keep the cylinder head temperatures below 500°F. (260°C.). Check the ignition timing.

Low Oil Pressure.—Low oil pressure or lack of pressure may be caused by any of the following:

Lack of priming. Disconnect the oil suction line and fill the pump with oil while the engine is being turned over.

Leak in suction line. Check very carefully for air leaks.

Oil pressure relief valve. Check the relief valve and spring for proper seating or breakage.

Dirt on oil screen in supply tank.

Crankshaft plugs leaking.

Excessive bearing clearance. If the bearings are worn excessively, the oil pressure will be lowered to approximately one-half normal pressure, which will necessitate an overhaul. After all other means of increasing oil pressure have failed, it indicates that the bearings must be badly worn or that something is seriously wrong and the engine should be removed for overhaul according to standard practice.

Check all oil lines.

Oil pump gasket. If the engine is started with very cold oil, the pressure is liable to get so high momentarily as to blow out the oil pump gasket.

Never change the oil pressure until it has been checked carefully with the engine warmed through thoroughly. The oil pressure is set correctly at the factory. A broken line or air leak or restriction in a suction line will cause variations in the pressure; these facts must be considered before regulating the pressure. The pressure gage should be checked for accuracy. Keep all suction lines clean, short, and of the full diameter size recommended. After checking the above, adjust the regulator. A quarter turn will cause several pounds variance. The pressure gage adjustment may be varied somewhat owing to the difference in cowling of various airplanes.

Overoiling.—If the engine appears to be receiving too much oil, it may be due to failure of the scavenger pump to prime. The pump is primed by a small hole drilled through the pump body from the pressure pump. This hole may have become plugged. Carefully check the sump suction line for air leaks.

If too much oil is thrown through the exhaust, or if there is frequent fouling of the spark plugs, it would normally indicate overoiling, caused by lack of seal of the piston rings, or a broken ring. Cylinders showing such symptoms should be removed and the trouble investigated.

After checking the above, and if the engine still throws oil through the exhaust stack, the bearings should be inspected for diametrical clearance. If this is over the limit as indicated in Table 2, the bearings should be replaced. A second kind of looseness is the clearance between halves of the connecting rod bearing shell. If there is *any* clearance there, the bearing should be replaced.

The oil drain holes in the oil ring groove on the piston may be plugged with carbon.

High Oil Temperature.—When the oil temperature is higher than recommended, investigation should be made to determine the cause. After due allowance has been made for atmospheric conditions, the trouble may be any one of the following:

Oil supply. There should be at least 3 gal. of oil in the circulating system.

Instruments. Check the oil temperature gage against one of known accuracy.

Insufficient cooling. It may be found that, owing to improper cowling, there is not enough circulation of air around the engine crankcase.

Lack of oil circulation. The failure of the scavenging pump to operate may cause the temperature of the oil in the crankcase to show an abnormal rise in temperature. Remove the pump and make sure the gears run freely.

Leaking Carburetor.—Leaking carburetor may be caused by

Leaky float
Stuck float
Needle valve not seating properly
Wear in float fulcrum pin
Leaking carburetor gasket

An engine should not be run if fuel leaks from the carburetor, because of the excessive fire hazard. Remove the carburetor and ascertain the cause.

In Cold Weather.—During cold weather, unless the plane is stored in a heated hangar, it is essential to preheat the oil. It is much easier to drain the oil at the termination of each day's flying, while the oil is still warm (as particles of carbon and metal are still in suspension), than after the oil has been allowed to cool.

There exists the possibility that after the oil is withdrawn, the pump may lose its priming; in this event, it should be primed either through the oil line or check valve. *Watch this very closely because the engine can be very quickly ruined if it is operated without the correct oil pressure.*

It is desirable to lag all external oil lines so that the oil does not congeal in them. A good material for lagging or insulation is asbestos cord wrapped around the pipes and covered with tape. It may be necessary in some cases to lag the oil tank also.

An air heater is installed on each engine. It is desirable to have it connected up at all times. The air heater cutout valve should be closed so that the exhaust will heat the air heater whenever the carburetor air temperature falls below 60 to 70°F. (15.6 to 21.1°C.). In warmer temperature, open the cutout valve, as the engine will lose power when the air is too warm.

Inspection and overhauling requirements and methods are much the same as on all engines of this size and type. Care must be taken that no parts are reassembled which are worn beyond the limits given in Table 2; all parts must be carefully inspected for defects of any kind.

Assembly.—The successful operation of the engine is absolutely dependent on careful attention to every detail in inspection and assembly. It should be remembered that the slightest neglect on the part of the inspector or the mechanic may result in the failure of the engine and possible loss of life.

Cotter pins and wires should never be used the second time. Never slack up a nut in order to line it up with the cotter pin hole. Use a plain washer if necessary.

Great care should be used to prevent dirt, dust, lock wires, nuts, washers, or other parts from falling inside the engine. These might work into the gears or oil lines, causing serious trouble.

All parts should be thoroughly cleaned and made free from grit before they are assembled in the engine. Use only clean whole rags.

As the engine will turn over a number of times before the oil pump will start to furnish a regular supply of oil, all bearing surfaces should be coated with a very liberal supply of good engine oil before assembly.

All spark plugs should be taken apart and cleaned. Never use emery cloth; use garnet, sandpaper, or a steel brush. Set the gap on B.G. spark plugs 0.012 in. Do not allow B.G. or any make of mica plugs to become soaked in gasoline.

For Champion spark plugs, see Table 2.

Assembling.—Assemble the crankcase to the stand.

Install the master rod and link rods.

Install the crankshaft.

Bolt up the master rod and safety the nuts.

Install the thrust bearing in proper position.

Install the front crankcase cover. Make sure that the oil passage seal is all right.

Make sure that the crankshaft has proper end play. Adjust the play by the shim placed between the front cover and the thrust bearing.

Install the valve tappet guides and valve tappets.

Install the oil thrower and front cover plate. Check to see that the nose cover plate has even clearance around the crankshaft.

Turn the engine in the nose-down position and install the cam and accessory drive gears.

Install the rear cover, making sure that the cover to the crankcase oil passages are all right and that the oil pump, etc., drives make proper mesh with their respective driving units. Also be sure that the magneto drive gear and coupling have approximately 0.010-in. end clearance after the magneto coupling is tightened in place.

See that the engine turns freely. If not, locate and remedy the trouble.

Install piston 1 and cylinder. The intake pipe should be loosely attached to the cylinder making sure that a new gasket has been used and that the flange and rubber gasket are placed on crankcase end of the same. Push rods and push rod housings should also be put on at same time as the cylinders making sure that a new gasket is used on the cylinder head end of the same.

Install the remaining cylinders as above.

Again see that the engine turns freely; if not, locate and remedy the trouble.

Install the oil sump, making sure that the screen gasket, etc., are in place.

Install the carburetor, making sure that the adapter is in place and that gaskets are in place and that nuts are properly tightened.

Install the carburetor air heater.

Install the fuel pump drive gears, making sure that they have the proper backlash.

Adjust the valve clearance: intake 0.020 in.; exhaust 0.020 in. when the engine is cold.

Time the magnetos. Right-hand, 25 deg. B.T.C.; left-hand, 27 deg. B.T.C.

Install the spark plugs.

Install the ignition wires.

More about Assembly. *Crankcase, Crankshaft, and Connecting Rods.*— After thoroughly cleaning with gasoline, bolt the case to the stand by at least four bolts. The crankshaft, with the main drive pinion bolted and keyed into place, should be inserted in place in the crankcase.

The two halves of the master rod, with link rods attached, should be put in the case before the crankshaft to facilitate assembly. Before these are bolted together, the bearing halves should be covered with heavy cylinder oil. Draw the four screws up evenly until tight and lock them with cotter pins. When drawn up tight, it should be possible to insert a 0.001 to 0.0015 feeler gage between the master rod proper and the cap close to the master rod bearing. This is done to secure a tight fit between the two halves of the master rod bearing.

The master rod and cap assembly are machined together as one unit. Never use a cap from one unit together with a rod from another.

The link rod pins in the master rod are of the automatic locking type. To remove a pin, press the plunger in the pin down flush with the surface of the

Table 2.—Fits and Clearances for Kinner B-5 and B-5R Series 2 Engine

Parts	Min.	Desired	Max.
	English units, In.		
Breaker gap in Scintilla magnetos PN-5D	0.012	0.012	0.015
Camshaft diametrical clearance in boss	0.003	0.0035	0.004
Camshaft, end play	0.010	0.015	0.020
Crankshaft diametrical clearance, main bearings	0.00175	....	0.002
Crankshaft, end play	0.008	0.010	0.012
Front cover to main crankcase	0.001T*	0.000	0.002L
Rear cover to main crankcase	0.003L	0.005L	0.007L
Master rod bearings on crankpin	0.0018	0.002	0.0022
Master rod, end play on crankpin	0.008	0.010	0.012
Magneto drive shaft, diametrical clearance	0.003	0.0035	0.004
Magneto shaft, end play	0.011	0.015	0.020
Oil retaining ring	Light press fit on crankshaft		
Oil pump drive shaft diametrical clearance:			
In body	0.0015	0.002	0.003
In cover	0.0015	0.002	0.003
Oil pump gears:			
Diametrical clearance in body	0.0005	0.001	0.0035
End play	0.0015	0.0025	0.0035
Oil pump gears diametrical on idler shaft	0.00175	0.0020	0.00275
Piston ring gap	0.012	0.015	0.017
Piston ring:			
In groove 1 top (side play)	0.003	0.0035	0.0045
In groove 2 (side play)	0.002	0.025	0.0035
In groove 3 (side play)	0.002	0.0025	0.0035
In groove 4 oil scavenger (side play)	0.002	0.0025	0.0035
Piston pin in piston	Push fit at 68°F. (20°C.)		
Piston in cylinder:			
On skirt	0.0195	0.020	0.0225
At top	0.0335	0.034	0.0365
Propeller hub diametrical clearance	Bearing 1 in. on big end, no bearing on small end		0.002
Propeller key fit:			
In hub	0.000	0.000	0.002L
In shaft	Light press fit		
Link rod:			
On lock pins	0.0008	0.001	0.0012
Side play	0.006	0.008	0.011
On piston pin	0.0008	0.001	0.0012
Spark plug:			
B.G. type 4-gap	0.012	0.012	0.015
Champion M-3-1	0.015	0.015	0.018
Tappet roller:			
On axles	0.0017	0.0020	0.0027
Side play	0.005	0.006	0.008
Tappet in tappet guide	0.0037	0.004	0.0048
Tappet guide in support in crankcase		Push fit	
Roller bearing in rocker arm	0.0001L	0.0006L	0.0011L
Roller bearing shaft:			
In rocker arm box	0.0000	0.0000	0.0005T
In roller bearing	Light push fit		
Rocker arm side play	0.008	0.011	0.016
Valve diametrical clearance:			
Exhaust	0.003	0.0035	0.004
Intake	0.0025	0.003	0.0035
Lock pins in master rod	0.0002T	0.0003T	0.0004T
Dowel pin in master rod bearing, diam	0.0000	0.0000	0.0015T
Backlash of fuel pump drive, beveled gears	0.008	....	0.015
Tappet clearance—cold engine 68°F.:			
Intake valve		0.020	
Exhaust valve		0.020	
Magneto timing:			
Right magneto 25 deg. B.T.C.			
Left magneto 27 deg. B.T.C.			

* The letters L and T mean "loose" and "tight" by the amount shown.

pin and push the pin out with the pin drift. Do not drive on aluminum plug as this is an oil seal. In assembling this unit, be sure that the plunger aligns with the hole in the master rod and snaps into place when pin is in place. As stated before, it should not be necessary to remove the link pin under 250 hr. In assembling the engine, the lock pin side of the master rod should be toward the front of the engine.

Front Cover.—The ball thrust bearing should be properly installed on the crankshaft. The front cover may now be put on and bolted in place. Care should be taken to see that the crankshaft has 0.006 to 0.012 in. end play with the front cover in place. If too much play is observed, use the proper thickness shim between the thrust bearing and the front cover. This is imperative. The oil thrower and front cover plate may now be installed. Check with a feeler gage to see that the front cover nose plate has equal clearance all around the crankshaft.

Carburetor.—Remove and clean the carburetor fuel screen. It should not be necessary to dismantle the carburetor unless it has been damaged. The carburetor and air heater may now be installed, using new gaskets between the adapter and the carburetor and the crankcase.

Cylinder.—The cylinders may now be installed, starting with No. 1. Each piston should be put on only as that cylinder to which it belongs is installed. Otherwise, piston rings or pistons may be scored or broken. Use new gaskets on the intake manifold. Insert the push rods, the exhaust tappet being nearest the cylinder. The tappet clearance should now be set as marked on the name plate. Be sure the cylinder being adjusted is at the top of the firing stroke.

Install the oil sump.

Valve Timing.—In assembling, cam 1 is the first one to install. With the crankshaft turned so that piston 1 is on top dead center, mark 1 in the main timing pinion will be opposite cylinder 1.

Mark "1" on the cam gear should mesh with mark "1" on the main timing pinion.

Cylinder Head Joint.—If for any reason a cylinder joint is broken, be sure to check the bearing of the barrel flange. Do this by using a surface plate and determine that the place of contact between the head and the barrel is in the inner circle. The outer circle should be approximately 0.005 to 0.007 in. lower. *Any time a cylinder head is removed from the barrel a new copper cylinder head gasket should be installed.*

Accessory Drives.—Laminated shims are provided for adjustment of the accessory drive bevel gears. The backlash between gears should be from 0.006 to 0.008 in.

LAMBERT ENGINE—R-266

This is a five-cylinder, radial engine which runs counterclockwise, as viewed from the propeller end. The horsepower rating is 90 at 2,375 r.p.m. The general dimensions are given in Table 3; the clearances are shown in Table 4.

The Lambert Aircraft Engine Corp. succeeded the Velie Motors Corp. as builder of the Velie M-5 aircraft engine, and later developed this more powerful Lambert model R-266. In designing the R-266, no material increases were made in the dimensions of the Velie M-5. The weight was slightly decreased and, at the same time, an increase of 38 per cent was made in the rated power.

The engine has clean lines and is easily cowled, owing to grouping the manifolding and valve gear back of the cylinders. The small over-all, 34¼ in., and the small number of cylinders keep head resistance down to a minimum. Light, heat-treated magnesium alloys are used for the crankcase and subsidiary castings.

The crankcase is of the two-piece type split on a plane through the cylinder centers. The intake passages and valve lifter guides are cast in the rear section in which the rear main bearing is carried in a steel retainer. Steel retainers in the front half carry the front main bearing and thrust bearing. The two crankcase sections are bolted together with accurately fitted ground bolts, and are finished machined in assembly to ensure alignment of bearings and cylinder pads.

The heat-treated chrome-nickel-steel crankshaft is of the two-piece, single-throw type. It is carried on three ball bearings, one on each side of the crank throw for radial load and the third near the front to take propeller thrust as well as radial load.

To make the assembly of a single-piece master rod, the shaft is divided into a front and rear section, the crankpin being integral with the forward, which transmits the power to the propeller. The rear section comprises the rear main journal and the rear crank cheek which is partly split and securely clamped over the rear end of the crankpin by means of a fitted ground bolt. Two locating dowels make possible repeated assembly and disassembly without special precautions against misalignment. The crankshaft is machined and ground in assembly and balanced by turning off the outer circumference of the bronze counterweights.

The one-piece heat-treated chrome-nickel-steel master connecting rod with steel-backed cadmium-silver bearing is designed to remain rigid at high speeds under the force of the explosions and the complex loading transmitted by the link rods. The link pins are secured by screws in flanges integral with the big end of the master rod. To the wrist pins are linked four heat-treated chrome-nickel-steel link rods. Both link pin and piston pin bearings are bronze bushed.

The pistons are special heat-resisting aluminum alloy cast in a permanent mold and heat-treated. Each piston has three heat-treated compression rings and one oil ring, the latter being above the piston pin. Oil return holes are drilled in the two bottom grooves of cylinders 4 and 5; only in groove next to the bottom of Nos. 1, 2, and 3.

The cylinder barrels, cast from fine-grained nickel iron, honed to form a polished, durable bearing surface, seldom need replacement. They are a slip fit in the cylinder heads and can be replaced if necessary, at minimum expense, without changing the heads. The cylinder heads are cast from the same heat-resisting aluminum alloys as the pistons, and are also heat treated. Each head has two Silchrome alloy valves and two spark plugs. The valve seats, valve guides, and spark-plug bushings are of special bronze. Triple round valve springs are employed.

The angles of the push rods and rocker arms have been chosen to minimize side thrust on the rocker shaft bearings. The rear ends of the rocker arms and the push rods are enclosed, and a special suction device largely prevents oil pumping of the valve lifters, which is a source of annoyance on many radial engines.

The gear case, a heat-treated magnesium alloy casting, carries the camshaft and the gear train which drives the cam, magnetos, and oil pump. A single three-lobe cam actuates both intake and exhaust valves through

Table 3.—General Specifications, Lambert R-266

Type	Air-cooled, static, radial aircraft
Number of cylinders	5
Bore, in	4.25
Stroke, in	3.75
Piston area, sq. in	14.186
Piston displacement, cu. in	53.197
Total displacement, cu. in	265.987
Compression ratio	5.55 to 1
85 hp. at 2,250 r.p.m.	
90 hp. at 2,375 r.p.m.	
Over-all diameter, in	34¼
Over-all length, in	30⅜
Weight dry minus propeller hub, starter, exhaust ring, and heater, lb	224
Weight per rated horsepower, lb	2.5
Propeller drive	Direct
Tachometer shaft speed	Same as engine speed on early engines.
Tachometer shaft speed	Engines from No. 3200 up, ½ engine speed.
Direction of rotation of tachometer shaft (looking into open end of tachometer drive on engine)	Clockwise
Diameter of mounting bolt circle, in	13¾
Number of mounting bolts	4
Size of mounting bolts, in. SB	½
Direction of rotation of magnetos (looking at breaker end of magneto)	Clockwise
Magneto speed	1¼ times crankshaft
Magneto spark advance, deg	25
Oil capacity, recommended, gal	2½
Spark plug	Champion M-3-1
Gap	0.015 to 0.18 in.
Valve tappet clearance cold (both valves)	0.010 in.

Valve timing—set exhaust 1 to close on top dead center with 0.060 in. tappet clearance.
Then set clearance up to 0.010 in., cold.
Carburetor—Stromberg NA-R3 with special discharge passage and accelerating mechanism.
Carburetor settings (average):

Venturi	1$\frac{5}{16}$ in.
Motoring jet	47
Economizer jet	54
Main air bleed	65
Well bore	28
Side holes in well, top to bottom 1 No. 60, 1 No. 58, 1 No. 56, 2 No. 46, 4 No. 44.	
Mixture control needle seat	18
Discharge hole, upper	46
Discharge hole, lower flush with lower edge of throttle	53
Idle air bleed	49
Syringe pump valve holes (4)	No. 52
Float level below parting line	$\frac{9}{16}$ in.
Hose connections (between engine and oil tank) ⅝ in. I.D.	

Note: The metering jet, economizer, or idle air bleed may vary on occasional engines. Check these sizes from the carburetor or from the engine manufacturer's records before ordering replacement carburetors. Each engine is tuned up individually.

Table 4.—Lambert Model R-266 Clearances

Piston, in	0.016
Piston rings (side clearance in groove), in	0.002
Piston ring (gap), in	0.015 to 0.025
Piston pin in piston	Push to light tap fit
Piston pin in connecting rod, in	0.001 loose
Wrist pin in master connecting rod	Drive fit
Wrist pin in connecting rod link, in	0.001 loose
Master connecting rod bearing, in	0.0025 to 0.003 loose
Valves in guides, in	0.003 to 0.004 loose
Rocker arm bushings,* in	0.0005 to 0.001 loose
Gear case bushings,† in	0.0002 to 0.003 loose

* These bushings are what is known as "Compo" bushings and can be assembled in the rocker arm only with the sizing arbor furnished with the tool kit. When pressed in with the sizing arbor and the arbor removed, they are the correct fit on the rocker arm shaft. These bushings are not to be reamed.

† It should be unnecessary to renew the gear case bushing for the first 1,000 hr. unless dirt and grit get into the lubricating system and cut them out badly. If it is necessary to renew these bushings, it should be done at the factory where fixtures for line-reaming them are available

roller valve lifters reciprocating in guides cast in the rear section of the crankcase. The gear-case cover, also of magnesium, carries the magnetos and oil pump and provides a mounting flange for a starter.

The lubricating system is of the pressure, dry sump type.

Ignition is furnished by two Scintilla SB5-L magnetos, with two spark plugs in each cylinder. On account of the rubber engine mount used with this engine, which insulates the engine from the fuselage, *be sure to have a ground return wire from the switch to some point on the engine.*

The Stromberg NA-R3 carburetor has an improved discharge system and a specially developed accelerating device. It is equipped with choker and altitude control and an economizer to reduce gasoline consumption at cruising speeds.

Assembling the Engine.—The successful operation of the engine is absolutely dependent on the attention given to every detail in inspection and assembly. It should constantly be borne in mind that the slightest neglect on the part of the inspector or the mechanic may result in failure of the engine and possibly the loss of lives.

Cotter pins and flattened lock washers should not be used again. Great care should be taken to prevent dirt, dust, cotter pins, lock wires, nuts, washers, and other small parts from falling into the engine. These might work into the gears or cylinders and cause great damage.

All parts must be thoroughly cleaned and free from grit before assembling. Clean them in gasoline and wipe with a cloth free from grit. *Do not use waste or tattered rags.*

Valve Timing.—To time the valves, proceed as follows:

Remove the propeller hub key and replace it with the timing pointer from the tool kit.

Turn the crank in the direction of rotation until the timing pointer is on top dead center mark on the outer rim of the front thrust bearing cover. Piston 1 is now on top dead center.

Now with the gear-case cover removed, remove three screws from the cam drive shaft gear timing flange.

Rotate the timing flange until exhaust valve 1 is closed and the valve lifter is on the low point of the cam.

Set exhaust valve 1 at 0.060-in. clearance between the rocker arm roller and the valve stem, as specified on the name plate. This will generally be between 0.060 and 0.075 in.

Rotate the timing flange counterclockwise until exhaust valve 1 just closes.

Replace the three screws in the holes in the flange that match with the holes in the cam drive-shaft gear and secure them with safety wires. If no three holes match exactly, it is better to time the exhaust to close slightly early, rather than slightly late.

Set all valves with 0.010-in. clearance between the rocker arm roller and the valve stem.

The ignition must now be timed so that the spark occurs *on the proper stroke* and with the proper advance.

Ignition.—The engines fire 1-3-5-2-4. The spark is timed 25 deg. before top dead center.

To time the magnetos, proceed as follows:

Secure the timing pointer from the tool kit in the propeller keyway in the crankshaft.

Turn the engine over in the direction of rotation until piston 1 is coming upon compression stroke. Stop when the timing pointer is opposite the mark on the front thrust bearing cover labeled "Mag. Adv."

Loosen the three nuts on each magneto coupling. Remove the distributor blocks.

Turn each magneto until the marks on the large distributor gear coïncide with the marks on the front end plate. Now tighten the nuts on the magneto coupling. The magnetos are now timed.

Remove the covers from the breaker housings and set the gap 0.012 in. on both magnetos on engines previous to No. 3225. The new Scintilla SB5-L need no adjustment of points. Keep them clean and see that they break at 25 deg. advance.

Ignition Cable Connections.—The cable connections from the distributor blocks to the spark plugs are as follows:

Socket in Magneto Distributor, No.	Spark Plug in Cylinder, No.
1	1
2	3
3	5
4	2
5	4

One magneto is connected to all front plugs and the other is connected to all rear plugs.

Ground Wire Connections.—These are on large fiber screw heads above the breaker covers of the magnetos.

Screw out the small brass screw leaving the socket free to receive the cable.

Push the cable in, full depth.

Drive the pointed end of the screw deep into the cable to make contact with the wire of the cable. On account of the rubber mounting used with this engine, it is important to see that a ground return wire is connected from the ignition switch to some point on the engine and is in good condition.

Before attempting to start the engine see that the ground wires are properly and securely connected, so that the magnetos will be grounded to the crankcase when the switch is off.

Attaching Propeller.—The propeller should be checked carefully for balance and tracked before it is placed on the engine. The taper on the crankshaft and hub must also be properly checked. If they do not fit, hand lapping will be necessary. Recheck the track after attaching the propeller to the engine. Be sure the propeller hub nut is securely locked. The large central nut and the nuts on hub bolts must be properly cottered.

Running in.—After overhauling, the engine must be run in carefully.

If a new master rod or other bearings or gears have been replaced, the engine should be given at least 10 hr. at gradually increasing speeds. If new cylinders, pistons, or rings have been installed, the engine should be given at least 8 hr., after which the cylinders should be removed for inspection. In any event the engine should be given 3 to 4 hr. of running in.

If the rocker arm bushings have been replaced, great care should be exercised to give them plenty of lubrication during the first 5 hr. They should be lubricated with the grease gun before being started; then after the first 2½ hr. and the first 5 hr. Thereafter they should be lubricated every 5 to 10 hr.

Avoid sudden acceleration of the engine. Run the engine at gradually increasing speeds to warm it up before flying; run it at gradually decreasing speeds to cool it down before switching off. Never run it wide open longer

than necessary either on the ground or in flight. Maintain the proper oil pressure and change the oil frequently in order to ensure long and trouble-free services from your engine.

General Information.—Any good aircraft engine should render dependable service for a long period of time without disassembly if it is kept clean, properly adjusted, and operated as recommended. It is highly desirable not to disassemble it any oftener than is absolutely necessary. Unless

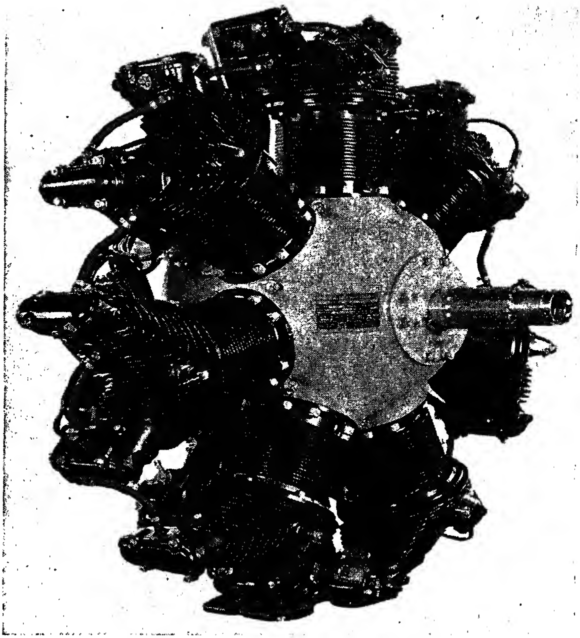


FIG. 6.—Warner 7-cylinder, radial engine.

of unusually complicated design, most troubles can be overcome by external adjustment. Those who develop extreme reluctance to disturb an engine usually get better service from it.

All radio-shielded installations must have a liberal sized ground wire or "jumper" between the fuselage and engine.

Do not let rubber bushings get too loose. Keep them snug.

With proper spark plugs and strainer, with gas lines clean, with magneto set right, and with proper valve clearance, the engine should run well.

It is perfectly normal for an engine to have a valve blow slightly after a flight, due to a particle of carbon under the seat or to warping slightly from being cooled down too quickly. This condition will usually take care of itself on the next flight. If not, open up the valve clearance on the particular

valve to about 0.030 in. and fly the ship 10 min. Then reset the clearance to normal (0.010 in.) and the valve will usually have seated itself. In any case, do not touch the engine as long as the full throttle ground r.p.m. does not show any appreciable drop. These valves when used with aluminum-bronze seats will usually reseat themselves without further leakage

WARNER SCARAB ENGINES

Scarab engines, built by the Warner Aircraft Corp., Detroit, Mich., are now available in four sizes, from 90 hp. in a five-cylinder engine to 175 hp. in a new seven-cylinder engine. This is shown in Fig. 6. The main dimensions of these engines are

Scarab Junior 40	
Five cylinders	90 hp. at 2,025 r.p.m. 94 hp. at 2,125 r.p.m.
Cylinder bore, in.	$4\frac{1}{4}$
Stroke, in.	$4\frac{1}{4}$
Piston displacement, cu. in.	301
Scarab 40	
Seven cylinders	125 hp. at 2,025 r.p.m. 131 hp. at 2,160 r.p.m.
Cylinder bore, in.	$4\frac{1}{4}$
Stroke, in.	$4\frac{1}{4}$
Piston displacement, cu. in.	422
Super Scarab 40	
Seven cylinders	145 hp. at 2,050 r.p.m. 152 hp. at 2,150 r.p.m.
Cylinder bore, in.	$4\frac{5}{8}$
Stroke, in.	$4\frac{1}{4}$
Piston displacement, cu. in.	499
Super Scarab 165	
Seven cylinders	165 hp. at 2,100 r.p.m. 175 hp. at 2,250 r.p.m.
Cylinder bore, in.	$4\frac{5}{8}$
Stroke, in.	$4\frac{1}{4}$
Piston displacement, cu. in.	499

Further details of these engines will be given later.

All references to the "front" of these engines means the propeller end of the crankshaft. The "right" and "left" sides of the engine are distinguished *from the rear* of the engine. The cylinders are numbered in the direction of rotation, clockwise when seen from the rear; counterclockwise from the front. Cylinder 1 is at the top. The push rods and cam followers are marked alphabetically, starting with *A* for the exhaust side of cylinder 1. The tachometer shaft speed is one-half crankshaft speed on all these engines.

Installation

Unpacking and Mounting.—The engine is shipped in a substantial crate with the crankshaft in a vertical position. The upper half of the crate is merely a cover, held in place with wood screws through the angle irons at the four corners.

The box, after the lid is removed, should be laid on the side next to the carburetor. *Care must be taken to see that the crate does not tip over when in this position.* The Scarab and Super Scarab engines can then be fastened to a hoist by means of the engine lifting eyes, which will be found at the rear ends of the two upper crankcase bolts. When a special tool is not available, use a wooden spacer or a piece of steel tubing approximately 18 in. long to hold apart the ropes or cables which lead from the lifting eyes to the hoist. On the Scarab Junior engine only one lifting eye will be found.

Before the engine is mounted in the airplane, great care must be taken to inspect the bosses on the mounting ring for flatness. They must be flat

within 0.003 in. if the engine is bolted up solidly, whereas a maximum valuation of 0.015 in. is permissible if wood veneer or suitable auto brake lining approximately ⅛-in. thick is used between the engine and the mount.

Rubber mounts of proper design and manufacture which allow no fore-and-aft motion at each mounting bolt and only a very limited flexibility to absorb the torque impulses in the radial direction may be considered satisfactory. Rubber motor mounts with excessive radial flexibility or with any appreciable fore-and-aft motion must not be used, as excessive stresses will be imposed on all engine parts from inertia and gyroscopic loads.

In installations where rubber bushings are provided at each mounting bolt to eliminate telegraphing of vibration to the fuselage structure, great care must be taken at the periodic inspection that these bolts have not become loose. These bushings are provided to eliminate the telegraphing of noises rather than to allow appreciable movement of the engine. All bolts must be equal in tension and as tight as possible without placing undue strain on them.

Regular 5⁄16-in. Aircraft bolts must be used for the installation of the engine to the airplane.

Fuel Supply.—The fuel line should be made from ⅜-in. O.D. tubing. A fuel strainer must be installed in the fuel line. A ¼-in. Briggs standard pipe tap is used on the carburetors for the later Scarab and Super Scarab engines; a ⅜-in. Briggs standard pipe tap was used on the earlier carburetors. The minimum fuel head from the bottom of the gas tank to the carburetor should be 20 in. when the plane is standing on the ground. Only gasoline hose marked with a red line corresponding to the Air Corps specifications should be used. All fuel lines should be made from seamless copper tubing which has been heated and quenched after bending. A ⅛-in. Briggs standard pipe tap is provided on the upper side of the top mounting lug for the installation of a primer.

Oiling System.—The oil tank should have a total capacity of approximately 6 gal. In service it should be filled with 5 gal. of oil, which allows an air space of approximately 20 per cent of the capacity, which is sufficient for the expansion of the oil. The oil tank should be located near the engine so that its lowest point is slightly above the oil pump when the airplane is standing on the ground.

The oil lines between the engine and the tank should be made from ¾-in. O.D. seamless copper tubing which has been annealed and quenched after bending to remove all stresses. A ⅝-18 tapped hole should be provided in the oil tank wall close to the bottom, or in the oil line from the tank to the engine for the oil thermometer. The oil thermometer used should have a range of 0 to 200°F. or 0 to 100°C. The drain plug in the oil tank and the oil outlet from the tank must be placed at the lowest point and the filler cap should be about 2 in. in diameter. A vent must be placed in the filler cap; when the ship is stunted frequently, a ⅜-in. O.D. vent tube should lead from the top of the tank to the ¼-in. pipe tapped hole provided for this purpose in the rear wall of the induction housing.

The oil pressure gage must be connected with a ⅛-in. Briggs standard pipe tap on the top side of the gear case by means of ¼-in. O.D. copper tubing. Use an elbow fitting at the gear case to clear the tachometer shaft. All engines furnished from the factory with a generator drive adapter are furnished with this elbow and a right-angle tachometer in place, as they must be installed before the generator adapter is mounted to the engine. The oil gage should read up to 150 lb. per sq. in.

Ignition System.—Scarab engines may use either magneto or battery ignition, but it is necessary to install the proper switch. Magneto switches must *ground* the ignition circuit; battery switches must *open* the circuit.

Cowling.—The cowling over the engine is attached by $\frac{5}{16}$-24 thread screws, two tapped holes being provided on the front side of each rocker arm. Where no air starter is used, the air starter boss on the cylinder head can be tapped in the same way and a special bracket provided. The cowling should never rest on the springs of the rocker arm housing cover. Where N.A.C.A. cowlings are used a cylinder head temperature indicator must be installed to take a reading at the rear spark-plug boss for test purposes.

Mounting the Propeller.—The propeller used should allow the engine to turn the maximum r.p.m. permissible at full open throttle in level flight. Such a propeller gives the best all-round performance of the plane, better fuel economy, and minimum stress on the engine. It is very important that propellers be carefully balanced and that they be fitted properly on the engine shaft. A shallow keyway may cause the hub to ride on the key and throw the propeller out of balance. The keyway should conform to S.A.E. specifications.

Unbalance may also be caused by a difference in taper between the engine shaft and the propeller hub. This should be carefully checked and the parts made to fit. If grinding, scraping, or lapping is necessary, both shaft and hub should be carefully cleaned with gasoline, and the parts well oiled before being put together. Castor oil is preferred for such cases as this. Be sure that the key is in place when the propeller is put on the engine shaft.

A propeller should "track" within $\frac{1}{16}$ in. at the tip. If the blades are adjustable, they should not vary more than $\frac{1}{4}$ deg. in angle. Propeller surfaces should be smooth; nicks and pitting should be smoothed with a fine file, abrasive cloth, and crocus cloth. Details of this will be found in the section on Propellers.

Periodic Inspection

The following inspection is recommended every 50 hr. Such regular inspection will give the most satisfactory engine performance and disclose defects otherwise likely to cause engine trouble. An engine properly cared for will give much more satisfactory service, the time between overhauls will be lengthened, and the total life of the engine will be considerably increased.

Check the tappet clearances, which should be between 0.008 in. min. and 0.012 in. max. for the intake and exhaust valves when the engine is cold. Proceed as follows: Turn the propeller forward until the intake valve on cylinder 1 closes, then turn propeller an additional 120 deg. (one-third full turn), which brings the piston to the top center. Insert the feelers between the valve stem and the rocker arm roller for measuring. Adjust to 0.010 if the clearance is found to be below 0.008 in. or above 0.012 in. When cylinder 1 has been adjusted, turn the propeller forward approximately 103 deg. which will bring one blade of the propeller into the same relation to cylinder 3 as it previously was in relation to cylinder 1. Check the clearance of cylinder 3 and then continue checking the clearances of cylinders 5, 7, 2, 4 and 6, in the sequence given, by turning the propeller in increments of approximately 103 deg.

Drain the oil; remove, clean, and replace the oil screen. Then fill the tank with the correct grade of oil in the quantities specified on the filler cap.

Check all bolts and nuts for tightness which are not secured by a lock wire or cotter pin. The magneto, starter, and generator attaching nuts are

most important. *Rocker arm housing cover nuts must at all times be tightened very moderately due to softness of the gaskets. Do not tighten these nuts unless there is indication of leakage.* Check the rocker arm shafts for tightness by applying a slight torque to the head of the bolts with a wrench. If loose, tighten the nut one castellation. Check the nuts holding the cam follower guide crabs, after removing the cotter pin, at the first 50-hr. check on a new engine or after a complete overhaul. Reinstall the cotter pins. Thereafter, these nuts need be checked only during each top overhaul when the cylinders are removed from the engine.

Check the throttle, mixture and spark controls, to be sure that the full movement of the controls in the cockpit corresponds with the full movement of the controls at the engine without excessive backlash.

Check the ground wire and its connection to the magnetos and ignition switch. It is very important that there be no break which might allow accidental starting of the engine with the ignition switch in the "off" position.

Check all high tension wires to be certain that the insulation is not damaged or being chafed by sharp edges.

Oil the magneto with S.A.E. 30 viscosity oil for average weather and S.A.E. 20 for cold weather. Put 30 to 40 drops into the drive end plate oiler. Any excess will drain away through the hole in the magneto base. Put only 5 to 8 drops in the breaker end oil cup, since over-oiling this end may interfere with the magneto operation if oil reaches the breaker contacts.

Check all spark plugs for tightness in cylinders. Do not disassemble any spark plugs or set up the gaps. They should be reconditioned every 300 hr. by an authorized service station having the proper tool equipment.

Inspect the valve gear with respect to springs, rocker arms, etc. The rocker arms and rollers must move freely.

Top Overhaul

A "top overhaul" includes grinding the valves and making the necessary adjustments of the cylinders and valve gearing. Frequency of top overhaul depends largely on operating conditions but generally varies between 250 and 600 hr. of operation. As long as the engine runs satisfactorily, it should be let alone up to approximately 600 hr., when a complete overhaul is recommended.

Need of overhaul depends largely on the r.p.m. of the propeller, with allowances for temperature and humidity variations. A drop of more than 100 r.p.m. beyond these figures indicates the need of a top overhaul. But before testing the ground speed to determine the need of overhaul, make the following checks:

Mixture—put in full rich position
Throttle—full open
Spark—fully advanced
Cylinders—all firing properly
Tappet clearances—0.008 to 0.012 in.
Magneto breaker gap—0.010 to 0.014 in.
Spark-plug gaps—0.015 to 0.020 in.
Nuts holding magneto—if loose, the magneto may move slightly and alter the timing.

Disassembling for Top Overhaul.—A top overhaul can readily be made with the tools in the tool kit without dismounting the engine from the plane. After removing the propeller, the cowling, and the exhaust pipes, clean the outside of the engine with gasoline.

To remove the cylinders from the engine, proceed as follows:

Remove the push rods by either removing the rocker arm sockets and pulling the rods out or by removing the rocker arms. The latter is recommended when removing the cylinders for top overhaul since the rocker arms must be removed in order to grind the valves.

Loosen the hose clamps and free the hose from the push rod tubes.

Remove first the palnuts from the cylinder hold-down studs and then remove the nuts, using the special wrench from the tool kit.

Each cylinder can then be removed as a unit with the push rod tubes and intake pipe. It will be found impossible to remove an intake pipe from a cylinder without removing the cylinder from the engine.

Remove the intake pipe.

Under no circumstances should the nuts be removed at the joint between the cylinder barrel and the cylinder head as this is a permanent joint.

While overhauling the cylinders, cover the crankcase openings with clean pieces of cloth for protection against dust and dirt. Determine which valves are leaking and need grinding by pouring gasoline into the valve ports. The valves needing grinding can then be removed with the valve-supporting tool and the valve spring-depressing tool. The large handle used with the cylinder wrench should be used with the valve spring-depressing tool.

Reconditioning and Valve Grinding during Top Overhaul.—After both valves have been removed, scrape off all carbon from the cylinder domes and valves, being careful not to mar or scratch the valve seats and stems.

Remove all the rings from the pistons. If the same rings are to be reinstalled in the engine, keep the rings of each piston stacked in sequence and number each stack since it is essential that all rings be reinstalled in the same piston grooves and in the same cylinders at the conclusion of the top overhaul. Scrape the carbon from the top surface of the pistons and then polish with kerosene-soaked crocus cloth. Remove all carbon from the grooves and rings, making sure that none of the rings are damaged. Inspect the pistons for cracks and check the piston pins for proper fit in both the piston and connecting rod bushing. Check the piston rings for gap and side clearance in the grooves, according to the Table of Fits, page 296.

If the engine is equipped with expander-type oil rings, it is strongly recommended that new expanders and shims be installed at the top overhaul in all cases. The use of new expanders greatly facilitates the reseating of the ring. Rings showing no scratches or other signs of wear may be reinstalled. Best results may be derived from the top overhaul if a new complete expander-type ring assembly is installed.

If there are any sharp edges and scratches on the pistons or in the cylinder wall surfaces, they should be carefully removed by stoning with a fine grade oil stone that has been dipped in kerosene.

Replacing Pistons.—When worn pistons must be replaced, the new ones must weigh within 1/4 oz. of the others in the engine. All push rod ball ends should be inspected for tightness on the rods.

A rocker arm roller that sticks, or shows signs of wear, or has excessive clearance should be replaced. This can be done in any authorized service station equipped with the proper tools, or at the factory.

Valves that show no leakage when tested with gasoline may be merely touched up with a good grinding compound; if worn, a good seat must be provided, not more than 1/8 in. wide. Valve grinding tools come in some tool kits or can be secured from the builders. After the valve seats have been ground, the valves and cylinders must be thoroughly washed. Some

exhaust valve seats are now faced with Stellite, which is very hard and wears but little. Others may require refacing with suitable cutters.

Simple and convenient fixtures for holding cylinders are used in repair work. They are frequently made of $\frac{3}{8}$-in. steel plate with suitable holes for the end of the cylinder and tapped holes by which the cylinder can be fastened to the plate.

Spark Plugs.—Check the fit of the spark plugs in the cylinders. This is necessary because of the possibility that, because of extreme temperature, the hole may have closed enough to make the plug fit too tight. A special tap is provided for such cases. The plugs themselves should also be carefully inspected.

Reassembling.—Be sure that all parts are perfectly clean and in good condition. Check all cam follower crab attaching nuts for tightness after removing the cotter pins and before installing the cylinders. Oil all bearings and other contact surfaces as the parts are put together. It is advisable to use new gaskets in all cases.

Cylinders.—Put the valves in place, being careful to get each valve with its proper cylinder. The cylinder number is etched on each valve stem below the groove. Snap the circlets, or spring rings, into their grooves from the side. Assemble the lower valve spring washer, springs, and upper washer to the head. All earlier Scarab engines used the same inner valve spring, but a heavier outside spring is used on the Super Scarab.

Early Scarab engines with a rocker arm housing cast on the cylinder, have a special tool for depressing the spring, so that the two halves of the split retainer can be inserted. Be sure the retainer halves used on each valve bear the same number. Where they are not numbered, as those used with autensic valves, they are interchangeable.

After the valves have been assembled, they must be tested with gasoline for tightness; if they still leak, the valve grinding must be repeated until they are tight.

After the valves are tight, assemble the rocker arms, if they have been removed. If, for any reason, a ball-bearing type rocker arm has been disassembled, the following procedure must be followed when assembling: Blow out the drilled oil passage in the rocker arm with an air hose, if one is available. The ball bearings must be assembled in the rocker arm with the shielded side toward the outside. Do not forget to place the small spacer between the two ball bearings. The bearings should have a push fit in the rocker arm. A ground steel washer $\frac{1}{16}$ in. thick is used between each ball bearing and rocker arm housing.

On the 29 Series Scarab, the inner and the outer races of the ball bearings are of equal width, and the steel washer is machined down to $\frac{1}{32}$ in. thick around the outer edge in order to provide clearance for the outer race of the bearing.

On the later Scarab and on the Scarab Junior, the outer race of the ball bearing is 0.342 to 0.346 in. wide, which is approximately 0.008 in. narrower than the inner race, and the steel washer is $\frac{1}{16}$ in. thick all over.

Care must therefore be taken when replacing a washer, that it *must be* the proper type. The thin-edge-type washer can be used interchangeably; the constant thickness washer must be used only with the ball bearing having the narrow outer race.

The cylinders are now ready to be replaced on the engine.

Assembling Pistons.—The combination piston rings assembly consists of a $\frac{1}{8}$ in. wide by $\frac{1}{64}$ in. thick shim on the Scarab and Scarab Junior engines,

and a $\frac{3}{16}$ in. wide by $\frac{1}{64}$ in. thick shim on the Super Scarab engines, a spring steel expander, and slotted type ring of proper width and diameter. It will be noted that the ring has no side clearance in the groove, the ring being elastic, owing to the slots.

The rings furnished by the Warner Aircraft Corp. are fitted and inspected in regard to the proper gap width. This should be 0.015 to 0.025 in.

If, on Scarab engines, a combination ring is to be installed on a piston fitted with a simple oil ring, the $\frac{3}{32}$ holes in the oil groove below the lowest ring should be enlarged by drilling them with a $\frac{1}{8}$ in. diameter drill, and four more $\frac{1}{8}$ in. holes should be added in the same groove. By drilling these holes, the efficiency of the ring will be improved.

The shim must be laid into the lowest piston ring groove so that it touches at the bottom all around, and so that it covers all the holes in case there are any. Care must be taken that the gap of the shim, expander, and ring are placed in relation to the stamped number on the piston exactly as shown. After the shim has been placed in the groove, the expander has to be put in with its gap opposite the shim gap. Last, the ring is put in the groove with its gap in line with the shim gap and opposite the expander gap. The ring must be put in the groove with the right side up, which will bring the chamfer, if any, on the ring toward the compression rings.

Pistons in the 165 Model.—In the 165 model a shim, a steel spring expander, and a slotted ring are used in the third piston groove. The ring has no side clearance in the groove, this not being necessary on account of the slots. New rings have a gap of 0.015 to 0.025 in. but will operate as long as the two ends overlap. On all pistons, except Nos. 5 and 6, the shim gap and ring gap must be on the exhaust side, and the expander gap on the intake side of the piston. *This is reversed on pistons* 5 *and* 6. The chamfer on the combination piston ring in the third groove must be toward the head of the piston.

The two compression rings must have the side clearance and gap specified in the Table of Fits on page 296. They should be installed so as to give about 120-deg. spacing between the three ring gaps in each piston.

Assembling Cylinders.—Do not interchange the valves from different cylinders. The cylinder number is etched on the valve stem below the retainer groove. The valve springs should be checked for tension as follows: The outer valve springs should show a pressure of 38 lb. min. when compressed to a length of $1\frac{37}{64}$ in.. The inner springs should show $30\frac{1}{2}$ lb. min. when compressed to $1\frac{1}{16}$ in.

The inner and outer valve springs have dampener coils at one end only. The dampener coils on the outer springs can be very easily recognized by the close spacing of the coils at one end. In the inner springs the dampener coils can be recognized but are less pronounced. On new valve springs the ends with the dampener coils are marked with red paint. It is imperative that the springs be installed with the dampener coils toward the cylinder head (away from the tip of the valve).

After the valves have been assembled, they must be tested with gasoline for tightness; if they still leak, the valve grinding must be repeated until they are tight.

If the intake pipe has been removed from the cylinder, install and line up as follows:

Attach the intake push rod tube to the cylinder with the intake pipe gasket in place; attach the intake pipe to the cylinder but leave the nuts loose. Slip the intake pipe gland and packing, without the spring, over the end of

the intake pipe, then install and attach the cylinder temporarily to the engine with several nuts drawn up tightly. While the intake pipe is so lined up, tighten the two intake pipe attaching nuts, remove the temporarily attached cylinder, and slip the hose and hose clamps over the push rod tubes. Install the spring, then the gland with the dished surface toward the packing, and then the packing over the end of the intake pipe. Install the piston in the cylinder with the numbered end toward the front. Push it in deep enough to get all the rings inside the cylinder but to leave the piston pin hole exposed.

Assembling Cylinders and Pistons to Engine.—Turn the crankshaft to the firing top center position. Install the well-oiled piston pin with the numbered end of the pistons to the front. Push the cylinder assembly into position with the intake pipe gland parts in place as explained above and attach permanently to the engine.

The palnuts locking the cylinder-attaching nuts should be tightened only one-sixteenth of a turn after they have been in contact with the nuts. Install the push rods and the rocker arms and set the tappets to 0.010 in accordance with the instructions for periodic inspection. A special wrench will be found in the tool kit to tighten conveniently the rocker arm socket lock nut.

After installing the rocker arm cover gaskets and covers, tighten the attaching nuts *very moderately*. Excessive tightening will cause the gasket to squash out, rendering it ineffective.

Complete Overhaul

When an engine has been in service 600 hr. or more, it should be completely overhauled. It is recommended that a complete overhaul be done only at the factory or at one of the authorized service stations having complete facilities and personnel to do the work properly. The magnetos and carburetor should be sent to a service station licensed and approved by the magneto and carburetor manufacturers. The continuous working and slight vibrations to which the carburetor is subjected have a tendency to change the float level with a corresponding change in fuel consumption. It is further recommended that all important steel parts of the engine be subjected to magnetic inspection during the overhaul. Since it is taken for granted that the complete overhaul is done by experienced licensed mechanics, the routine procedures of assembling and disassembling are omitted and only the important steps are covered here. Note should be taken of all defects or excessive clearances observed during the disassembly and inspection.

Disassembling for Complete Overhaul.—After the engine has been removed from the airplane and attached to a suitable assembly stand, thoroughly wash the exterior with gasoline and remove the ignition harness and all accessories. The induction housing cover, which is the large casting in the rear of the engine, is removed. Next remove the large cotter pin through the starter jaw and the nut from the center of the jaw, using a 1⅛-in socket wrench. The magneto drive gear and the crankshaft gear can then be removed. The crankshaft assembly cannot be pulled out when removing the crankcase, as outlined below, until the above gears are removed from the crankshaft extension shaft as it is pinned to the crankshaft. Remove all other gears that can be pulled out. There are no timing marks on any gears and the engine will have to be retimed. Instructions are given on page 294.

Turn the engine so that all cylinders are in a horizontal plane. Remove the cylinders as in the top overhaul. Loosen the thrust bearing retaining

nut. No locking device is employed on this nut since the rear propeller hub cone, when the propeller is installed, acts as a lock. This nut is drawn up very tightly so a special well-fitting wrench is required. Remove the seven nuts from the six crankcase bolts and stud. Then drive the bolts as far back as possible, except the two on each side of cylinder 1. There is a stud between cylinders 4 and 5 which, of course, cannot be driven back.

For models 165*B and* 165*AB*, which are equipped for a controllable pitch propeller, proceed disassembling the engine in the following order:

Remove the controllable pitch propeller valve assembly screwed into the front of the crankcase.

Take off the thrust bearing cover.

After the cover is removed, an open hole is exposed, at the top, in the machined face of front crankcase. Through this hole, screw in tightly a 12-24 screw, 1⅛ to 1¼ in. long, using a large-diameter flat washer under the head. The washer must be flat and free from burrs so as not to mar the machined face of the crankcase. This screw engages with the controllable pitch propeller valve housing, consisting of a tube-shaped section cast into the side of a collar. The end of the tube fits into the bottom of the valve hole in the crankcase. The collar is a running fit over a spacer on the crankshaft.

Caution. Never attempt to pull the front crankcase off the crankshaft until the 12-24 screw is in place, for it clamps the valve housing while the crankcase is being pulled from the crankshaft, thus preventing the valve housing from getting cocked and causing it to bind.

Pull the crankcase with a crankcase puller, as in all models. Tapping around the case with a wood or fiber block will help take it off without cocking. Put the engine under a chain hoist with the propeller end of the shaft up. Screw the propeller nut on the shaft and pull a rope or wire sling through the large holes in the nut. It is then easy to pull the crankshaft out of the rear crankcase, tapping with a wooden mallet if necessary. This cannot be done unless the gears have been removed from the end of the crankshaft extension.

The crankshaft should next be clamped in a vise with copper-covered jaws gripping *one* counterweight only, so as not to spring the shaft. The lock ring, rear bearing retaining nut, rear ball bearing, and the pin holding the extension shaft should be removed and the extension shaft pulled out of the crankshaft.

From the front crankcase remove the 12-24 thread screw and pull the valve housing out from the valve hole. Then remove the thrust bearing by tapping. The valve housing can then be tipped and taken out through the main bearing opening in the rear. Remove the loose front crankcase washer if it is still there.

Model 165*D*.—For model 165D, which is equipped for a constant-speed propeller, unscrew the elbow connection from the tube located in the front of the crankcase.

Remove the gland, packing, and tube guide from the crankcase.

Unscrew the tube with the special long socket wrench in the tool kit.

Never pull the crankcase off the crankshaft until this tube has been removed.

Remove the thrust bearing cover.

Pull the crankcase off the crankshaft as described.

For model 165 and 165A, first remove the thrust bearing cover; then pull the crankcase.

Remove the connecting rod assembly from the crankshaft. The link rod locking bolts should be removed next to inspect the fit of the wrist pins in the link rods, which must be a tight push or light drive fit. Oversize pins must be fitted if necessry. Care must be taken when removing the link rods from the master rod to insert a steel wedge between the link rod and master rod so that the pin bolt bushing will not be disturbed when driving the wrist pin out of the link rod. It will be noted that these bushings are not flush with the inner surface of the master rod and would be moved outward if no wedge were used.

Inspecting and Reconditioning.—After the engine is disassembled, clean all parts in kerosene, rinse in gasoline, and dry. Inspect all parts on a clean bench and, if necessary, recondition them in accordance with the following instructions:

Check all clearances according to the Table of Fits, page 296. If the permissible clearance is exceeded, the worn part must be replaced; wherever the old part shows any markings for assembly purposes, the new parts should be marked correspondingly.

Any new parts put into the engine must be carefully fitted to the specified clearances.

Inspect the crankcase for burrs on the parting surfaces between the two halves and on all other machined surfaces. Inspect the main bearing sleeves for tightness. They are shrunk into the crankcase and should under no circumstances be removed, since sleeves once removed cannot be reinstalled properly. The cam follower guides should have a light push fit in the crankcase. If they are found to have clearance, new oversize cam follower guides should be installed which, in some cases, may require reaming of the crankcase to obtain the proper fit.

If the bearings are found loose in the crankcase, they should be replaced with bearings that are oversize on the outside diameter. All ball bearings should be purchased from the Warner Aircraft Corp., especially the thrust bearing and front main bearing which are specially manufactured for this engine. The front and rear halves of the crankcase are machined together as a unit and can not be replaced separately.

All bushings in the induction housing are line reamed after being pressed in place. Whenever a bushing is being replaced, it should be done at the factory or in a shop having the proper facilities for lining up and boring the bushings. An assembly drawing giving the correct dimensions should be requested from the Warner Aircraft Corp. before the work is undertaken.

Inspect the crankshaft for straightness. This operation has to be performed with extreme care, particularly in the event that the engine was in a plane that had been nosed over. The shaft without the ball bearings should be supported in two large V blocks on the ball-bearing surfaces next to the crank cheeks. Rest the blocks on a surface place high enough to allow the shaft to be rotated without touching the surface plate. While turning the shaft, an indicator must show not more than a total reading of 0.004 at the front end of the shaft. In the same setup, inspect the crankpin for being parallel with the main journals. This must be done for two positions, with counterweights pointing down and to the side. In either position the indicator must not show more variation than 0.002 between the two ends of the crankpin. A sprung shaft cannot be straightened and must not be used, because it would result in very rough operation and ultimate failure. Inspect the journals and the crankpin for roundness. All oil passages must be blown out to remove any fine particles of dirt, etc.

Measure the crankpin with a micrometer for out-of-roundness and taper which should not exceed 0.003 in. Crankshafts with wear beyond the above value should have the crankpin reground to 1.867 in. plus or minus 0.005 in., using bearing shells bored 0.008 in. undersize in diameter. If any connecting rod bushings need replacement, reaming will be required after they have been pressed in. A well-equipped machine shop may be able to bore the bushings, in which case an assembly drawing giving the correct dimensions should be requested from the builders.

The fit of the wrist pins in the link rods should be carefully checked. It is very important that the pins be a tight fit in the link rods and that they cannot be turned easily when testing them with a suitable tool engaging the slots in one end of the wrist pins. If a loose wrist pin is replaced by one of oversize diameter, the bushings in the master rod may possibly have to be reamed out to obtain the proper fit.

Check all link rod bolts. They should be replaced if they are not the latest bolts. New bolts are considerably stronger than the old ones. In addition, the sections locking the wrist pins are surface-hardened to eliminate wear. They can be distinguished by the length of the undercuts and center section as shown in Fig. 7. Some of the earlier model 165 engines were equipped with bolts that do not have a second undercut next to the thread. Some Series "40" and "50" engines were equipped with bolts having two ¼-in. wide undercuts and center section 2⁹⁄₆₄ in. wide. Do not use bolts for replacements. For assembling new bolts, see page 290.

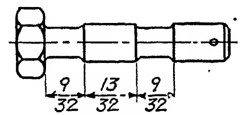


FIG. 7.—Bolt used in link rods.

The cam ring has a floating bronze bushing which can be replaced. The flange on the bushing must be pointing forward when installed. Top-overhaul the cylinders as outlined under Top Overhaul. Install the rocker arms in the cylinders only after the cylinders have been installed in the engine and after the valve timing has been done as previously explained.

If it is necessary to replace valve guides, all burrs must be removed on the protruding inner end of the valve guide. Heat the cylinder heads with a torch to approximately 300°F. and pull or drive out the valve guides with suitable tools. The new guides should be cold when driven in and the temperature of the head around 280°F. It is important that they be driven until the shoulder of the guide touches the cylinder head. After the head is completely cooled, recut the bronze intake valve seat and regrind the steel exhaust valve seats, piloting from the valve guide. The least possible amount of material should be removed from the seats. If the seat surface after cutting is wider than ⅛ in., it should be reduced to that width with a 15-deg. cutter.

Oversize Parts.—A number of oversize parts are available, which have been found most essential in servicing operations.

For the grinding of cylinder bores which are badly worn or scored, the Warner Aircraft Corp. has adopted 0.010 in. oversize as the smallest oversize standards in conformity with S.A.E. standards, and pistons can be furnished for this oversize. On all Series "50" and previous engines, 0.012 in. will be maintained as the first standard oversize.

If a stud must be replaced, the following instructions should be observed. All original studs have a 0.005 in. oversize pitch diameter (P.D.) at the screwed-in end to obtain a tight fit in the aluminum part. If a stud has worked loose, or is otherwise damaged, it must be replaced by one with a

larger P.D. and is indicated by "-O" added to the part number. These studs are designated as oversize P.D. studs. They should be used only when the thread in the aluminum has not been damaged.

If, by excessive tightening, the thread in the aluminum part is stripped, the hole may be tapped out to a 1/16 in. larger size using a new stud with a 1/16-in. larger thread at the screwed-in end. These are called "oversize shoulder studs" and are indicated by adding "-OS" to the number. Use only ground taps for S.A.E. standard threads. The P.D. of the tapped hole should be from standard to 0.002 in. over standard. The following tap drill sizes must be used:

For 5/16-24 thread use 17/64 drill
3/8-24 thread use 21/64 drill
7/16-20 thread use 3/8 drill

Assembling.—After all parts are inspected and properly reconditioned, assemble the engine as follows:

Be sure all parts are cleaned and generously oiled on all moving surfaces as they are being put together, also that dirt does not get into the engine during the assembling. A lock washer must be used on all plain nuts with the exception of the cylinder attaching nuts on which a palnut is used. See Top Overhaul for the correct installation of the palnuts. With all castellated nuts use a cotter pin but no lock washer.

In either case, if the nut goes against an aluminum part, a plain washer must be used next to the aluminum. If the nut makes contact with a steel or bronze part, no plain washer is used.

Be sure to add the cotter pin or the lock wire where required, as soon as the parts are put together. It is advisable to use new cotter pins and new lock wire when reassembling an engine. For lock wire, metallic belt lacing approximately 0.047 in. in diameter is recommended.

It is very important that steel cotter pins of the proper diameter and length are used in all places. The following pin sizes should be used:

1/16 in. diam. × 1/2 in. long...........	all 1/4-in. and 5/16-in. castellated nuts
3/32 in. diam. × 5/8 in. long...........	all 3/8-in. castellated nuts
	rocker arm shaft nuts
	magneto drive shaft nuts
1/8 in. diam. × 5/8 in. long............	propeller hub nut
	master rod bolt nuts
1/8 diam. × 3 in. long................	crankpin plug
	starter jaw retaining nut

Install the cam follower guides, cam followers, cam ring, cam ring bushing with its retaining ring, and the crankcase bolts in the rear crankcase. Then attach to the induction housing which should be mounted on an assembly stand.

When installing a link rod bolt (Fig. 7) in the connecting rod assembly, proceed as follows:

Be sure to use the nut that is furnished with the bolt as it is especially inspected for close tolerances of the squareness of the face in contact with the link rod.

Install all link rod bolts with the threaded end toward cylinder 1, as shown in Fig. 8 and with the cotter pin hole in the position shown in Fig. 9; especially when installing during a top overhaul, in order to facilitate the insertion of the cotter pin.

Tighten the nut snugly with a wrench to draw the head of the bolt against the link rod.

Loosen the nut and tighten with the fingers.

Observe the relation between the cotter pin hole in the bolt and a castellation in the nut.

Tighten the nut from approximately three-eighths of a castellation (approximately 16½ deg.) to a maximum of 1¼ castellations (approximately 75 deg.), as shown in Fig. 9. (This method of tightening has been found more satisfactory than using a torque wrench which is influenced by the amount of lubrication and the fit between the nut and bolt.)

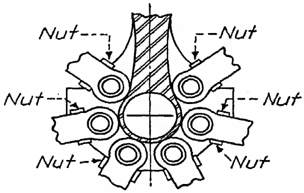


FIG. 8.—Position of link rod bolts in place.

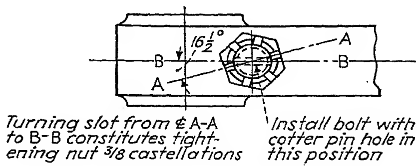


FIG. 9.—Tightening nut on link bolt rod.

Install a cotter pin, as shown in Fig. 10. Be sure to bend both ends of it as indicated; do not bend one of them over the end of the bolt since otherwise an adjacent link rod may strike it.

Hold the crankshaft in a vise, gripping *both cheeks*, as shown in Fig. 11, and install the extension shaft and pin, rear ball bearing (with chamfer toward cheek), its retaining nut and lock ring.

Next, grip the front cheek of the crankshaft in a vise as shown in Fig. 12 and install the connecting rod assembly with the markings toward the front. Draw up the master rod bolts with a wrench slightly over finger tight. The hole in each bolt should line up with a slot in the nut. If they are not lined up while in this position, switch nuts as each nut has been selected when assembled at the factory. Then tighten all four nuts evenly, one castella-

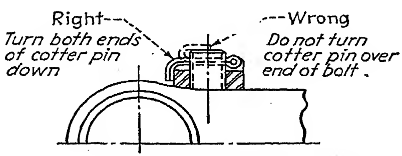


FIG. 10.—Bend *both ends* of cotter pin *down*.

tion in order to obtain a stretch on the bolts of 0.004 to 0.006 in. which is the maximum allowable.

While the parts are being assembled to the front end of the crankshaft, it should stand vertically with the rear ball bearing resting on a bench or wood or fiber support in which there is a 3⅛ diam. hole. To prevent springing the crankpin, use a small block or jack between the counterweights. Install the front main bearing against the crankshaft cheek, making sure the large chamfer on the bearing faces toward the cheek.

While the crankshaft remains in this position, install the front crankcase, proceeding as follows:

For Models 165*B and* 165*AB*.—Install the propeller valve housing in the front crankcase, holding it in place *loosely* with the 12-24 screw used in disassembling. *Do not* tighten this screw as the housing must center itself on the crankshaft. With the front crankcase in a vertical position, front

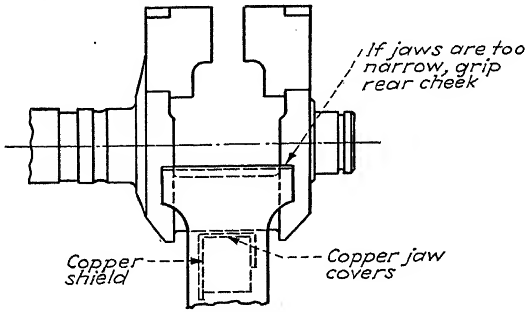


FIG. 11.—Grip both cheeks in vise like this to install extension shaft.

facing up, lay the front crankshaft washer on top of the valve housing with the chamfer facing forward, then press the thrust bearing into position in the crankcase, with the bearing chamfer facing toward the rear.

Install one of the crankshaft washers on the crankshaft against the main bearing, with the chamfer to the rear. Next install the crankshaft spacer

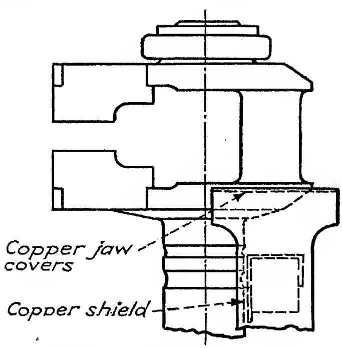


FIG. 12.—Grip the front cheek this way to install connecting rod assembly.

against the washer with the narrow relief groove on the outside diameter toward the rear. Then drop the front crankcase assembly on the crankshaft, keeping the crankshaft square, and at the same time oscillating it, to prevent

the valve housing from binding on the crankshaft. The crankcase should then be forced into final position by pressing or tapping on the inner race of the thrust bearing while oscillating the case.

Install the oil slinger and thrust bearing nut.

Install the crankshaft and front crankcase assembly to the rear crankcase as explained below for all models.

Remove the 12-24 screw holding the valve housing, and install the propeller valve and parts. Make sure the valve is installed with the partial shoulder toward the front so that when in position the shoulder is opposite the stops on the end of the valve housing, allowing the valve to turn only 90 deg.

For Model 165D.—Install the crankshaft spacer on the crankshaft against the main bearing with the notched end facing the front. The rings must be in position on the spacer as follows: Each ring groove contains a bronze and cast-iron ring with the bronze ring on the outside; that is, toward the ends of the spacer. The markings on all the rings must face inside; that is, toward the center groove of the spacer. Next, oil generously and slide the crankshaft collar over the spacer with the countersunk end toward the rear, while compressing the rings without marring them.

Install the thrust bearing in the front crankcase with the bearing chamfer facing the rear. Then drop the crankcase assembly on the crankshaft and force into final position by pressing or tapping on the inner race of the thrust bearing.

Install the oil slinger and thrust bearing nut.

Install the crankshaft and front crankcase assembly to the rear crankcase as explained below, For All Models.

Next install the tube in the front crankcase by rotating the crankshaft until the threaded hole in the crankshaft collar is opposite the hole in the crankcase boss. It may be necessary to shift the collar back or forth on the spacer in order to line up the threads. This can be done by inserting some suitable tool through one of the cylinder openings and a hole inside the crankcase. To prevent oil pressure leakage, the tube must be screwed tightly into the collar, using the special long socket wrench.

For Models 165 and 165A.—Install crankshaft spacer on the crankshaft against the main-bearing.

Install the thrust bearing in the front crankcase, then drop the crankcase assembly on the crankshaft and force it into final position by pressing or tapping on the inner race of the thrust bearing. Install the oil slinger and thrust bearing nut.

For All Models.—With the small block or jack between the counterweights still in place, install the crankshaft and front crankcase assembly to the rear crankcase, preferably by means of a chain fall as explained for disassembling. Force the assemblies into position by pressing or tapping on the thrust bearing nut.

Tighten the thrust bearing nut very tight to prevent wear and damage to the crankshaft in operation.

Then determine the proper thrust bearing cover gasket thickness as follows:

Be sure that the thrust bearing is driven against the shoulder in the crankcase assembly.

Place the cover over the crankcase without a gasket.

Hold the cover firmly against the thrust bearing and check with a feeler the clearance between the cover and the crankcase.

Install one or a combination of thrust bearing cover gaskets so that the combined thickness of the gaskets is equal to or 0.003 in. more than the space measured with the feeler. Thrust bearing cover gaskets are available in thicknesses of 0.003 in., 0.005 in., and 0.015 in.

It will be found that some end play may develop in the crankshaft in service. This is in no way detrimental.

After the intake pipes have been properly aligned as explained under Top Overhaul, install the pistons and cylinders to the engine.

Valve Timing.—The engine is now ready for valve timing, which requires a timing disk. One space in the crankshaft spline is blocked with a small screw which may be located at the center line of the crankpin on some engines or at 90 deg. with the crankpin on other engines. Bring the piston of cylinder 1 to the top center position. Then put the timing disk on the crankshaft with the "O" and "TC-1" markings at the top. The number of teeth in the gear train has been chosen so that timing in increments of six crankshaft degrees can be obtained by differential action as outlined below. The timing consists of three steps: (1) the preliminary timing before the rocker arms are installed to prevent moving valves from striking the piston while the engine is being turned; (2) installation of the rocker arms in cylinder 1 and setting of the required tappet clearance; (3) accurate timing.

Preliminary Timing.—This is done as follows:

Install the crankshaft gear on the crankshaft extension shaft, making sure that both keys are in place.

Install the push rods in cylinder 1 only and turn the cam ring until the exhaust push rod just indicates closing and the intake push rod indicates opening. The cam ring can be turned either by means of the crankshaft with the cam drive idler shaft in place or by turning the ring only through the holes in the induction housing without the cam drive idler shaft in place.

Leaving the cam ring in this position and without the cam drive idler shaft in the engine, turn the crankshaft to put the piston of cylinder 1 into the top center position.

Install the cam drive idler shaft as follows: Engage successively three *adjacent* teeth of the small gear on the cam drive idler shaft with the gear on the cam ring, without turning the cam ring. It will be found that for one of the three engagements the large gear on the cam idler shaft will allow meshing with the crankshaft gear with but very little turning of the crankshaft.

For Tappet Setting.—Turn the crankshaft, with the cam idler shaft installed as heretofore described, one full turn, bringing piston 1 into the top center position of the firing stroke. Install both rocker arms in cylinder 1 and set the tappet clearance on both valves to 0.027 for timing. Check the valve timing, using a 0.0015 feeler. The timing should conform as closely as possible to the following specifications:

Exhaust opens 60 deg. B.B.C.; closes 10 deg. A.T.C.
Intake opens 10 deg. B.T.C.; closes 60 deg. A.B.C.

Accurate Timing.

1. To change timing 18 crankshaft degrees;

a. Lock the cam ring by inserting a special bolt, as in Fig. 13, in the $\frac{5}{16}$-24 tapped boss to the right of the crankshaft gear in the induction housing and screw it against the cam ring. This bolt should be tightened only moderately against the cam ring; excessive tightening may cause damage. This bolt may be purchased from the Warner Aircraft Corp.

b. Pull the idler shaft out so that its large gear is just out of mesh with the crankshaft gear without pulling the small gear of the idler shaft out of mesh with the gear of the cam ring. Turning the crankshaft *one* tooth space in the direction of the advance-retard arrows appearing on the induction housing at the right of the crankshaft gear and then meshing the gears by pushing the idler shaft in, changes the timing 18 deg.

c. If the timing is not completed, loosen the cam ring lock bolt before attempting to turn the engine for checking. It is imperative that after the timing is completed, this locking bolt be completely *removed* from the engine.

2. To change timing 12 crankshaft degrees;

a. Lock the cam ring as already outlined.

b. Mark the meshing tooth on the crankshaft gear and corresponding space on the idler shaft with a pencil.

c. Pull the small gear of the cam drive idler shaft carefully out of mesh with the gear on the cam ring and turn the idler shaft in the direction indicated by the retard-advance arrows just above it until the *second next* tooth on the small gear is in mesh with the cam ring. Then turn the crankshaft in the direction of the advance-retard arrows, at the right of the crankshaft gear, until the marked tooth of the crankshaft extension gear meshes with the *sixth*

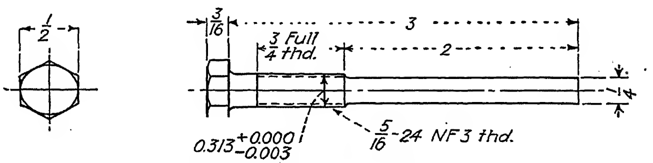


FIG. 13.—Special bolt to hold cam ring for timing valves.

space from the marked space on the large gear of the idler shaft, and then push the idler shaft fully in.

d. If the timing is not completed, *loosen* the cam ring lock bolt before attempting to turn the engine for checking. It is imperative that after the timing is completed, this locking bolt be completely *removed* from the engine.

3. To change timing 6 crankshaft degrees:

a. Lock cam ring as outlined above for the 18-deg. change.

b. Mark the gear teeth as outlined above for the 12-deg. change.

c. Pull the small gear of the cam drive idler shaft carefully out of mesh with the gear on the cam ring and turn the idler shaft in the direction indicated by the retard-advance arrows just above it until the *next* tooth on the small gear is in mesh with the cam ring. Then turn the crankshaft in the direction of advance-retard arrows at the right of the crankshaft gear until the marked tooth of the crankshaft extension gear meshes with the *third* space from the marked space of the large gear of the idler shaft, and then push the idler shaft fully in.

d. If the timing is not completed, *loosen* the cam ring lock bolt before attempting to turn the engine for checking. It is imperative that after the timing is completed, this locking bolt be completely removed from the engine.

After the valve timing is correct, install immediately the magneto drive gear with the starter jaw to the crankshaft extension shaft and tighten the nut and cotter key properly. This will prevent the cam drive idler shaft from falling out accidentally, causing the valve timing to be lost when changing the position of the engine. After inserting all the other gears, install the

Table 5.—Fits of Warner Engines

In replacing bushings or valve guides the outside diameter of the new part must be measured and compared with the size of the hole. The press fit must be within limits specified in the table. Particular care must be taken in fitting new ball bearings. The inside diameter of the inner race and the outside diameter of the outer race must be checked for correct fit as specified in the table.

	Min., in.	Max., in.
Bushings and Guides (Press Fit)		
Piston pin bushing in connecting rods, diam.	0.002T	0.004T*
Wrist pin bushing in master connecting rod, diam.	0.002T	0.004T
Extension shaft bushing in induction housing, diam.	0.002T	0.005T
Cam drive idler shaft bushing in induction housing, diam.	0.002T	0.005T
Generator drive shaft bushing in induction housing, diam.	0.002T	0.005T
Pump drive shaft bushing in induction housing, diam.	0.0015T	0.0035T
Pump drive idler gear shaft bushing in induction housing, diam.	0.0015T	0.0035T
Magneto drive shaft bushing in induction housing, diam.	0.0015T	0.0035T
Accessory drive idler shaft bushing in induction housing, diam.	0.0015T	0.0035T
Valve guides (intake and exhaust) in cylinder head, diam.	0.0012T	0.0028T
Crankshaft Ball Bearings		
Crankshaft thrust, front and rear ball bearings:		
On crankshaft, diam.	Light tap fit	Tight push fit
In crankcase, diam.	Light tap fit	Tight push fit
Crankshaft thrust bearing in crankcase, end.		
Rocker Arm Ball Bearings		
Rocker Arm Ball Bearings:		
On rocker shaft, diam.	Sliding fit	Light push fit
In rocker arm, diam.	Push fit	Tap fit

Piston Pin	Min. clearance	Max. allowed clearance, due to wear	Desired clearance
Piston pin in piston, diam.	Slide or push fit when piston is at room temperature		
Piston pin in connecting rod, diam.	0.0008L	0.0025L	0.001L
Piston and Piston Rings			
Piston skirt bottom diameter in cylinder	0.019L	0.025L	0.020L
Compression ring in piston, side	0.002L	0.008L	0.004L
Compression ring, gap	0.009L	0.030L	0.015L
Oil regulating ring (combination in piston), side		None	
Oil regulating ring (combination), gap	0.015L	0.035L	0.020L
Oil Pump			
Pump Drive Shaft in Oil Pump:			
Diameter	0.0005L	0.002L	0.001L
End	0.004L	0.019L	0.010L
Pump gears in oil pump, end	0.001L	0.005L	0.0025L
Pump idlers shaft in gears	0.0005L	0.002L	0.001L
Rocker Arm			
Rocker Arm Roller:			
On roller sleeve, diam.	0.0005L	0.006L	0.001L
In rocker arm, end	0.004L	0.010L	0.006L
Tachometer Drive Shaft			
Tachometer drive shaft in housing, diam.	0.0005L	0.0025L	0.001L
Tachometer driven shaft in housing:			
Large diam.	0.0005L	0.003L	0.001L
Small diam.	0.0005L	0.003L	0.001L
Cam, Magneto, Oil Pump, and Generator Drive			
Crankshaft extension shaft in bushing, diam.	0.001L	0.005L	0.002L
Cam drive idler shaft in bushing, diam.	0.0012L	0.005L	0.002L
Magneto drive shaft in bushing, diam.	0.0007L	0.0035L	0.0015L
Pump drive and idler shaft in bushing, diam.	0.0007L	0.0035L	0.0015L
Accessory drive idler shaft in bushing, diam.	0.0007L	0.0035L	0.0015L
Generator drive shaft in bushing, diam.	0.001L	0.004L	0.002L
Connecting Rods			
Bearing Shells in Rod—End.	0.0000	0.002L	
Crankshaft in shells when installed in rod:			
Diam.	0.0017L	0.0035L	0.002L
End	0.006L	0.013L	0.008L
Link rod in master rod, end	0.005L	0.012L	0.007L

* The letters L and T mean "loose" and "tight" by the amount shown.

Table 5.—Fits of Warner Engines (*Continued*)

Piston Pin	Min. clearance	Max. allowed clearance, due to wear	Desired clearance
Wrist Pin			
Wrist pin in bushing, diam.	0.0007L	0.0025L	0.001L
Wrist pin in link rod, diam.	See Complete Overhaul—Inspecting and Reconditioning		
Cam Ring			
Cam ring on bearing sleeve, end	0.002L	0.016L	0.008L
Wall thickness of floating bushing	0.0575 thick	0.0565 thick	
Gears			
Gears (all), backlash (when cold)	0.003L	0.012L	0.006L
Valves			
Exhaust valve in valve guide, diam.	0.002L	0.006L	0.0025L
Intake valve in valve guide, diam.	0.001L	0.004L	0.0015L
Cam Follower			
Cam follower in guide, diam.	0.0005L	0.004L	0.001L
Cam follower guide in crankcase, diam.	Light push fit		
Cam follower roller on sleeve, diam.	0.0005L	0.002L	0.001L
Cam follower roller in cam follower, end	0.006L	0.011L	0.006L
Models 165B and 165AB Parts for Controllable Pitch Propeller			
Oil valve in housing:			
Diam.	Sliding fit		
End	0.003L	0.025L	0.008L
Crankshaft spacer in valve housing, diam.	0.002L	0.005L	0.003L
Model 165D Parts for Constant-speed Propeller			
Governor drive bushing in housing, diam.	0.002 tight		0.004 tight
Governor drive shaft in bushing, diam.	0.0008L	0.003L	0.001L
Governor drive shaft in housing, end	0.005L	0.020L	0.008L
Crankshaft spacer in collar, diam.	0.002L	0.005L	0.003L
Pair of rings in collar groove, side	0.003L	0.007L	0.004L
Cast-iron ring, gap	0.005L	0.025L	0.008L
Bronze ring, gap	0.002L	0.015L	0.005L

induction housing cover. If a starter is used on the engine, it should be installed before the installation of the magnetos.

Magneto Timing.—The preliminary magneto timing is obtained by changing the mesh between the magneto drive gear and the gear on the magneto shafts. The final timing is obtained by turning the magneto in the range allowed by the slotted attaching holes.

For the preliminary timing proceed as follows: Turn the engine slowly in direction of rotation until the piston in cylinder 1 comes up on the compression stroke, and stop when reaching the specified ignition timing in fully advanced position, using the timing disk. Set the magneto to full advance by turning the lever in a counterclockwise direction, as seen from the rear. Remove the distributor blocks and turn the magneto shaft in the direction of rotation until the timing marks on the large distributor gear correspond with those on the front end plate. There are two sets of these timing marks, consisting of one and two lines each. Therefore, make sure when timing to line up the proper marks in this position. The magneto couplings, which have previously been attached to the magneto drive shaft, will be at a certain angle.

If one magneto is equipped with an oil seal flange on the coupling, *it must be installed on the right side of the engine.* If the slot in the magneto drive shaft is not in the proper position, remove the ¼-in. hexagon head cap screws at the bottom of the magneto attaching pad of the engine. Pull the magneto drive shaft out as far as the induction housing cover allows and then turn the gear before remeshing it until the slot appears to be parallel to the coupling on the magneto. Remember that turning this shaft counter-

clockwise *advances* the timing; turning it clockwise *retards* the timing. Install the magneto, using the gasket and the special large washers under the attaching nuts. Tighten the nuts only sufficiently to hold the magneto firmly in place but still allowing it to be turned.

Final Timing.—Tapping the magneto clockwise advances the timing; tapping it counterclockwise retards the timing. To determine the breaking of the points, insert a 0.0015-in. feeler between the breaker points. If the engine cannot be correctly timed within the range of the slots, the coarse timing has to be reset. After the timing has been completed, the ¼-in. cap screw must be installed, using a copper asbestos gasket, and lockwired. This cap screw prevents the coarse timing from being lost if the magneto has to be removed in the field.

The timing can be preserved in an emergency if a magneto has to be removed, by scratching a line on the magneto flange and induction housing cover to which the same magneto can be reinstalled. If only one magneto has been removed, it should be timed so that its timing corresponds to the undisturbed magneto. If the cap screw has been lost, a new one can be installed the length of which must not exceed $1\frac{1}{16}$ in. as measured from the bottom of the head to the end. A longer cap screw may cause damage to the engine by touching the running gear in operation.

When the magneto advance rod is installed, put both magneto levers in the fully advanced position, then adjust the length of the rod to suit.

When installing the magneto blocks, make sure that the grooves at the bottom of the blocks rest squarely on the pins in the magneto.

After the magneto timing, complete the assembling of the engine. On all unshielded and Air Associates shielded ignition harness, the right magneto fires all rear spark plugs and the left magneto fires all front plugs. When Breeze shielding is installed, the right magneto will fire all front spark plugs and the left magneto will fire all rear spark plugs.

SECTION IX

SMALLER ENGINES

CONTINENTAL A-40 AIR-COOLED ENGINE

This is the smallest of Continental engines. All are four-cycle, four-cylinder, horizontal opposed, air-cooled engines. There are four series: 2, 3, 4, and 5. Series 2 and 3 are rated at 37 hp. at 2,550 r.p.m.; Series 4 and 5 at 40 hp. at 2,575 r.p.m. Their general dimensions, seen in Fig. 1, follow:

Table of Specifications, Series 2, 3, 4, and 5

Bore and stroke, in.	$3\frac{1}{8} \times 3\frac{3}{4}$
Displacement, cu. in.	115
Compression ratio	5.25 to 1
Firing order	1-3-2-4
Direction of rotation (facing propeller end)	Counterclockwise
Lubrication	Single Vane type pressure pump
Oil pressure, lb. per sq. in.	30–40
Materials and Accessories	
Crankcase	One piece cast aluminum alloy
Cylinders	Nickel iron, cast in pairs
Cylinder heads	Aluminum alloy
Crankshaft	One piece alloy steel, drilled for pressure lubrication to main and connecting rod bearings
Main bearings	2 main bearings, lead bronze
Connecting rod bearings:	
Series 2 and 3	Drop-forged steel with cadmium-nickel lined crankpin bearings and bronze piston pin bushings. (Can be replaced with Series 4 and 5 type)
Series 4 and 5	Crankpin bearing—replaceable steel back lead-bronze lined. (Not used on early Series 4 engines)
Pistons	Full trunk type, cast aluminum alloy with full-floating pin
Piston rings	1 oil control, 3 compression
Valve gear	Camshaft—alloy steel; tappets—cast iron with chilled radius ends, chevron packed against oil leakage
Valves	Heat-resistant stainless-steel exhausts; hardened-steel intakes
Propeller shaft at hub	S.A.E. No. "0" tapered
Propeller hub	Hub for wooden propeller furnished as standard equipment.
Carburetor	Vertical, single Stromberg model NA-S2
Magneto:	
Series 2, 3, and 4	Single Bosch type FF-4A, or Scintilla type PN4-DF1, or Bendix-Scintilla type SF-4L
Series 5	Two Bendix-Scintilla type SF-4R
Spark plugs	Champion M-3-1 or BG4-B2
Tachometer drive	Standard S.A.E. connection. Clockwise rotation at one-half engine speed
Operation	
Maximum r.p.m.:	
Series 2 and 3	2,680
Series 4 and 5	2,700
Cruising r.p.m.	2,250
Recommended gasoline	72 octane aviation, or better
Gasoline consumption (max.), lb. per hp.-hr.	0.75
Gasoline consumption (cruising), U.S. gal. per hr.	2.8
Oil consumption (max.), lb. per hp.-hr.	0.025
Oil consumption (cruising) (max.) pt. per hr.	½
Capacity of oil sump, U.S. qt.	4
Recommended top overhaul	Every 200 hr.
Recommended major overhaul	Every 500 hr.

Table of Specifications, Series 2, 3, 4, and 5 (*Continued*)

Engine Timing	
Valve clearance for timing:	
Exhaust, in.	0.020
Intake, in.	0.025
With above clearance (Series 2):	
Intake valve	Opens 10 deg. B.T.C.; closes 55 deg. A.B.C.
Exhaust valve	Opens 55 deg. B.B.C.; closes 10 deg. A.T.C.
Running cold clearance, in.	0.015
With above clearance (Series 3, 4, and 5):	
Intake valve	Opens 10 deg. B.T.C.; closes 50 deg. A.B.C.
Exhaust valve	Opens 60 deg. B.B.C.; closes 15 deg. A.T.C.
Running cold clearance, in.	0.015
Magneto fires:	
Series 2	27 deg. B.T.C.
Series 3, 4, and 5	22 deg. B.T.C.
Dimensions and Weights	
Over-all height, in.	20 7/16
Over-all width, in.	26 7/16
Over-all length, in.	27 15/16
Mounting bolt centers	8½ in. wide; 10⅝ in. high
Dry weight (with carbon and magneto):	
Series 2, 3, and 4, lb.	144
Series 5, lb.	154
Weight of propeller hub	3 lb. 9 oz.
Shipping weight:	
Series 2, 3, and 4, lb.	255
Series 5, lb.	265

Figures 4 and 5 show a larger engine and the following list names the parts that are lettered in these illustrations.

A = Tachometer drive S.A.E. standard, one-half engine speed, counterclockwise rotation
C = Name plate
D = Oil pressure gage connection, ⅛ pipe tap
E = Oil thermometer connection, S.A.E. standard
F = Exhauts mounting face
G = Oil screen
H = Oil pump
I = Oil pressure relief valve
J = Oil drain
K = Primer jet
L = Carburetor mixture control
M = Fuel inlet connection
N = Breather connection, ⅝ in. I.D. hose
O = Oil quantity gage
P = Starting motor, S.A.E. standard small-type mounting

Installation.—All cowling should be arranged so that the air flow past the cylinders is not obstructed in any way. The crankcase should be shielded from the slip stream except for operation in very warm climates, otherwise the oil temperature will be too low and the warm-up period too long. All shielding should be removable for summer operation.

The gas line should be free from any kinks or bends that tend to cause air locks, and an approved flexible joint should be incorporated to prevent cracking of the tube from vibration. The gas supply should have a minimum head of 12 in. A primer should be installed for convenience in starting. The jets should be screwed into the underside of each head, into the tapped holes that are provided for that purpose. The propeller should be chosen to permit the engine to turn approximately 2,550 r.p.m. in full-throttle level flight (not over 2,680 r.p.m. on Series 2 and 3, or 2,700 r.p.m. on Series 4 and 5).

Operation instructions are similar to those for models A-50, A-65, and A-75, beginning on page 308.

Overhaul.—After the engine has been removed from the plane, the spark plugs should be taken out and stored in a safe place free from dirt. These can be removed by using a tool furnished with the service tool kit.

Remove the ignition wire conduit by unscrewing the $\frac{3}{8}$-in. nuts, one on either head holding down the front conduit brackets.

Remove the two $\frac{5}{16}$-in. nuts on the rear crankcase cover holding down the rear conduit brackets. Remove the magneto distributor blocks (Scintilla PN4-DF1), or distributor cap (Bosch FF-4A), or unscrew the four knurled thumb screws and pull out the ignition wires (Bendix-Scintilla SF-4L or SF-4R) from the magneto. Disconnect the ground wire. Remove the magneto, or magnetos (Series 5), by unscrewing the $\frac{5}{16}$-in. magneto mount-

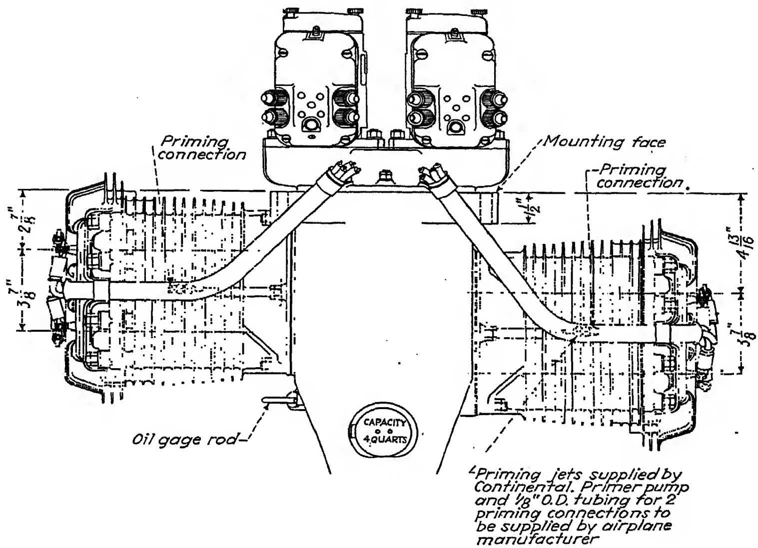


Fig. 1.—Top view of 40-hp. Continental model A40-50.

ing nuts. After removing the magneto, all blocks and caps should be replaced to avoid the possibility of foreign matter getting into the magneto and causing it to short out.

Remove the carburetor by unscrewing the four $\frac{1}{4}$-in. nuts that hold the carburetor to the crankcase. All the foregoing parts should be placed in a safe place free from dirt.

Remove the intake and exhaust manifolds by unscrewing the two $\frac{5}{16}$-in. nuts at the intake flange to the crankcase and unscrewing the four $\frac{5}{16}$-in. *brass nuts* at the exhaust manifold to the cylinder block on either side. The intake and exhaust manifolds can now be removed easily.

Cylinders 1 and 3 are now ready to be removed. First turn the crankshaft until the keyway is on top or in line with the serial number on the case.

This puts the pistons halfway up the bore of the cylinders, and eliminates any chance of breaking the piston rings. Remove the six 7⁄16-in. nuts holding the cylinder to the crankcase. The cylinder can now be pulled off the pistons.

After cylinders 1 and 3 have been removed, the head can be taken off by unscrewing the fifteen ⅜-in. nuts. After the nuts have been removed, a hammer handle can be inserted into the cylinder bore and the heads tapped

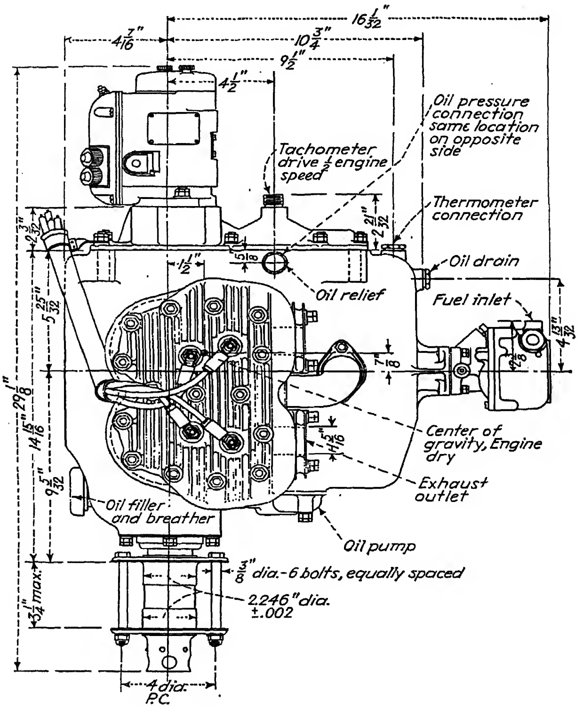


Fig. 2.—Side dimensions of same engine.

Valve springs can now be removed by inserting the valve spring compressing tool between the first and second fins on the base of the cylinder block. By exerting downward pressure on the handle, the valve spring retaining pin can be withdrawn with the fingers. After the springs are removed, care should be taken not to mix the valves. Exhaust 1, intake 1, etc., should always remain in their respective places.

The pistons may be removed from the connecting rods by pushing out the piston pin with the finger, or tapping lightly with a soft aluminum drift.

When the piston is very cold, it may be necessary to warm it slightly before the pin can be removed.

Leave the crankshaft in place and remove blocks 2 and 4 in the same manner.

When the pistons have been removed from the connecting rods, the connecting rods themselves can be removed by unscrewing the two $\frac{9}{16}$-in. nuts on each rod bearing. Some A-40 engines are equipped with connecting rods having replaceable lead-bronze crankpin bushings. These bushings may be removed by simply forcing them with the fingers after the cap has been removed from the rod. Care should be taken to see that all bushings are kept so that each may be replaced in the exact position from which it was removed.

After both blocks and all pistons have been taken off, the tappets can be removed. Unscrew the four $\frac{5}{16}$-in. nuts holding down the valve tappet guide plates, and the tappets can be pulled out. By inserting the finger in the tappet hole, all packings and glands may be lifted out.

The oil pump can be removed from the front of the crankcase by unscrewing the four $\frac{5}{16}$-in. nuts. The crankshaft oil seal plate on the front of the case can be removed by unscrewing the four $\frac{5}{16}$-in. nuts.

The rear cover plate can now be taken off by unscrewing the thirteen $\frac{5}{16}$-in. nuts that hold it to the crankcase. On the dual-ignition engine, four of these nuts come within the rear cover and are lock-wired for absolute safety. After the cover is removed, remove the shim on the rear bushing support, being careful not to bend or break it. The camshaft can then be pulled out the rear by hand. Care should be taken not to mar the bearings with the cam lobes.

Remove the crankshaft by tapping the propeller end of the shaft with a hide mallet. The shaft will slide out. The rear bearing support will come out with the crankshaft.

Remove the crankshaft cam drive gear from the crankshaft by unscrewing the four $\frac{1}{4}$-in. cap screws. Where dual ignition is used, this gear is held to the shaft by four studs and nuts, lock-wired together. Remove the wire and nuts. The gear can now be tapped off with a hide mallet and the rear bearing support removed from the shaft to allow inspection of the rear main bearing.

The last part to be removed is the oil screen, which lies under the camshaft and extends the full length inside the case, being held in place with four lips, one on each corner. By bending these up, the screen can be removed and cleaned. (This screen is not used on all models.)

The desired fits are shown in Table 1.

Inspection. *Crankshaft.*—Clean the crankshaft oil pressure holes thoroughly with clean gasoline, and blow out with air. Inspect the journals for scuffing; check the journal fillet for cracks, also the main bearing for cracks or checks.

Connecting Rods.—Inspect the rod bearings for cracks or checks. If cracks or checks are visible, the rod should be rebushed. If the rod has replaceable bushings, only the bushing need be replaced. If not, return the rod to the factory, for exchange for a rebushed rod. Check the bronze piston pin bushings for scuffing or overheating. If the bushing appears burned or rough, put in new.

Piston, Piston Pins, Piston Rings.—See that no rings are stuck in the grooves. If so, remove all rings, clean the carbon from the ring grooves and head of the piston; also clean carbon from the inside of the piston ring.

Do not polish the contact surfaces of the piston. If slight score marks are visible, stone lightly with a fine Pike stone. If scoring is heavy, the piston must be replaced. Inspect the piston pin for excessive heat marks. If "blued," discard. If pin bosses are worn, put in new. If the piston rings are "feathered" or show brown score marks, put in new.

Cylinder Blocks.—Check for scores. Very light scores can be removed with crocus cloth. If the cylinder has heavy scores, the block should be replaced by a new one.

Valves.—Recut all valve seats; reface all valves, replacing those that do not clean up on a valve-refacing machine. Regrind all valves. Do not polish the valve stems as it removes the hard glaze which is desirable. Check all valve springs for wear, tension, and breakage.

Camshaft.—Inspect lobes on the cam. If scuffed, stone lightly. Inspect the cam bearings for scratches. If the cam lobes are scuffed, the cam followers are probably also scuffed and will have to be stoned lightly on the inner ends.

Crankcases.—Check the case thoroughly for fatigue cracks. Clean with gasoline, blow out all oil holes.

Pressure Relief Valve.—Clean thoroughly and reinstall. The plunger should work freely in its cage without sticking.

Magneto.—Inspect the points and true them up if pits are visible, making sure that the points are flat against each other. Oil only according to the magneto instruction book. Inspect the wiring harness. If any wires are damaged, they should be replaced. See that all wires are well anchored and that positive contact is made.

Carburetor.—The carburetor needs practically no attention aside from draining the float bowl of water, which can be done by removing the ¼-in. pipe plug in the bottom of the float chamber.

Cylinder Heads.—The cylinder heads should be cleaned of carbon and lapped on a surface plate until they are absolutely flat.

Gaskets and Packings.—It is always the best policy to use new gaskets and packings throughout whenever reassembling an engine.

Assembling the A-40.—The A-40 is a very simple engine and can be assembled in a comparatively short time. *All parts must be thoroughly cleaned before the assembling operations are started.*

Slip the rear bearing support over the end of the crankshaft after first using a generous amount of clean oil on the bearings. Fasten the crankshaft cam drive gear with the four ¼-in. cap screws or the four studs and nuts, whichever the case may be. These four holes are not equally spaced, so it is impossible to get the gear on incorrectly.

The crankshaft can now be assembled to the case by inserting the propeller end of the shaft through the rear of the crankcase, being careful not to mar the front main bearings.

The oil screen can be put in and the four clamping lips forced down against the case with a screw driver. (This screen is not used on all models.)

The cam can now be assembled to the case, using a generous amount of oil on the cam bearings before assembly and seeing that the cam bearings are not nicked or marred as the cam lobes pass through the bearings.

The crankshaft cam drive gear is marked with center punch marks on adjacent teeth. The cam shaft gear is marked with one center punch mark on the tooth. *This should mesh with the cam gear mark between the two marks on the crankshaft gear.* If this is meshed according to the marks, the valves are properly timed. The rear bearing support is cut away to allow the camshaft gear to go up flush and eliminate any possibility of the cam gear's

cutting the rear bearing support. *Always see that this cut is at the bottom of the case.*

Place the shims that control the crankshaft end play over the studs of the rear bearing support.

The rear cover plate can now be installed, making sure that the tachometer drive is entered into the elongations in the center of the camshaft. Tighten the thirteen 5/16-in. nuts. Before safetying the nuts, check the crankshaft end play. This clearance should be 0.010 to 0.020 in., measured between the crankshaft and rear crankshaft bushing flange.

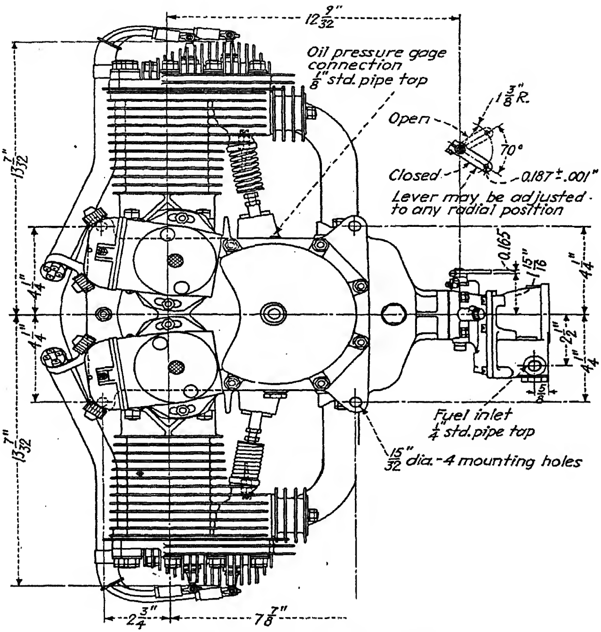


Fig. 3.—End mounting dimensions.

Assemble the oil pump blade and body to the front of the crankcase. Tighten the four 5/16-in. nuts and safety them.

The cam followers or tappets can now be inserted. When tightening down the tappet guide plate, see that the tappets work freely in the guide. If binding, loosen the nut and shift the guide plate a little one way or the other. The tappets must not bind on these guide plates. If the tappets work freely tighten the nuts and safety them.

The connecting rods are offset and must be assembled correctly. The rods are numbered on the upper and lower bearing corresponding to the cylinder number on the case. *All rods are assembled with the number toward the top of the crankcase.*

If the rods are of the replaceable bushing type, either a new bushing should be supplied or the old one returned to its exact former position. *Always replace both halves of the bushing when either is damaged.* Never replace only one-half of the bushing. The bushing may be slipped into the rod, or cap end, by aligning the slot in the bushing with the slot in the rod and pressing in on the center of the bushing with the fingers.

The bushings are made in such a manner that once they are snapped in place, they will stay by their own tension. They may easily be removed but will not become dislocated during assembly. All connecting rod bushings are manufactured to size at the factory, and no further fitting is required at installation.

All connecting rods with permanent crank-end bushings require no further fitting.

After each rod is drawn up tightly in its respective place and safetied, the pistons may be installed on the rods. These are also numbered on the relief side of the pistons and *the numbers should face the propeller end of the crankshaft.* It is better to install only two pistons at a time, in order that they will not become scratched during succeeding operations. Put on pistons 1–3 first. Set the piston ring gaps at approximately 90 deg. from each other around the piston.

Cylinder block 1–3 can now be put on. First see that the keyway on the crankshaft is in line with the engine serial number on the front of the case. With the shaft in this position, pistons 1–3 will be out of the case about half-way. Move one piston about 1 in. farther out than the other. This will allow you to start one piston into the block over the three top rings.

Oil the piston and cylinder bore thoroughly with clean oil. Start the piston in the block holding the block horizontal and the piston will slide in very easily. This operation may be facilitated by the use of a piston ring clamp. Tighten the six 3/8 nuts and safety. Proceed in the same manner with block 2–4. These blocks can be identified for right and left by the number on the machine surface of the block; No. "1" on the block corresponds to No. "1" on the case, etc.

After the cylinder blocks are on and safetied, the clearance should be set to 0.015 in. on all tappets. A 0.015-in. feeler gage is furnished with the service tool kit, also two tappet wrenches. Turn the crankshaft until cylinder 1 is on the firing stroke. The piston is on top dead center when the keyway on the shaft is on the center line of the cylinder. Set the tappets by loosening the jam nut and screwing the tappet in or out until the 0.015-in. clearance is obtained. Now draw the jam nut up snug, proceeding in the firing order, which is 1-3-2-4. After the clearances are properly set, the magneto should be timed.

Magnetos.—The Bosch FF-4A, Scintilla PN4-DF1, and Bendix-Scintilla SF-4L magnetos are used on the single ignition A-40; the Bendix-Scintilla SF-4R is used on the dual ignition A-40. All are timed in approximately the same manner, the only difference being in the determining of when the magneto is set to fire cylinder 1.

For the Bosch, the mark on the distributor block designated "L" should point directly upward in line with the mark on the magneto housing. For the Scintilla, the mark on the distributor gear should be brought into alignment with the mark on the magneto housing. The Bendix-Scintilla magneto has a small window on the top forward part, which shows a gear and a fixed pointer. One gear tooth has been cut off at an angle; when this tooth is in line with the pointer, the magneto is set to fire on cylinder 1.

Table 1.—Fits of Continental A-40, Series 2, 3, 4, 5

	Nominal	Desired fit	Tolerance	
Piston in cylinder:				
Lands		0.0255L	0.024L	0.027L*
Skirt		0.0155L	0.014L	0.017L
Piston ring in groove:				
Top compression		0.0032L	0.0025L	0.004L
2d compression		0.0027L	0.002L	0.0035L
3d compression		0.0017L	0.001L	0.0025L
Oil control		0.0017L	0.001L	0.0025L
Piston ring gap:				
Compression		0.012	0.007	0.017
Oil control		0.011	0.007	0.015
Piston pin in cylinder		0.0155L	0.013L	0.018L
Plug in piston pin		0.001T	0.0005T	0.0015T
Piston pin in piston		0.0004L	0.0001L	0.0007L
Piston pin in rod		0.0016L	0.0013L	0.002L
Piston pin bushing on connecting rod		0.003T	0.002T	0.004T
Connecting rod bolt in rod		0.0005L	0.0015L	0.0005T
Bearing shell in connecting rod (crush)		0.001T	0.0004T	0.0015T
Bearing shell key in connecting rod		0.008L	0.004L	0.012L
Connecting rod to crankpin:				
Diameter		0.0018L	0.0008L	0.0028L
End play		0.0075L	0.0055L	0.0095L
Crankshaft in crankcase, end play		0.015L	0.010L	0.020L
Crankshaft in front bushing, diam		0.002L	0.001L	0.003L
Crankshaft in rear bushing, diam		0.0025L	0.0015L	0.0035L
Crankshaft in crankshaft gear		0.0007L	0.002L	0.0005T
Crankshaft oil plugs, cheeks		0.0015T	0.0005T	0.0025T
Crankshaft oil plug, front (Thread P.D.) (Series 3 after and including engine 539)		0.003L	Size	0.006L
Crankshaft oil plug, rear		0.006T	0.0035T	0.0085T
Crankshaft oil plug (crankpin) (Series 3 after and including engine 539)		0.010T	0.007T	0.013T
Propeller hub nut on crankshaft (Thread P.D.) (Series 3 after and including engine 539)		0.0035L	0.0001L	0.0069L
Propeller hub key in crankshaft		0.0002L	0.0015L	0.001T
Propeller hub key in hub		0.0005L	0.0015L	0.0025L
Propeller hub flange on propeller hub		0.006L	0.002L	0.011L
Propeller hub bolt in hub and flange		0.017L	0.005L	0.030L
Crankshaft front bushing in crankcase		0.0025T	0.0015T	0.0035T
Crankshaft rear bushing in support		0.0027T	0.0015T	0.004T
Bushing support in crankcase		0.002L	0.0005L	0.0035L
Pin in crankshaft and camshaft bushings		0.0015T	0.0005T	0.0035T
Bushing support in cover		0.0015L	0.0005L	0.0035L
Tachometer bushing in cover		0.0013T	0.0007T	0.0018T
Camshaft rear bushing in crankcase		0.0027T	0.0015T	0.004T
Camshaft front bushing in crankcase		0.0017T	0.001T	0.0025T
Oil relief valve in crankcase		0.0075L	0.006L	0.009L
Oil filler body in crankcase		0.008T	0.0055T	0.0105T
Camshaft drive gears (P.D.) to centers		0.0035L	0.001L	0.006L
Camshaft gear to camshaft		0.0007L	0.002L	0.0005T
Camshaft in rear bushing		0.0025L	0.0015L	0.0035L
Camshaft in front bushing		0.002L	0.001L	0.003L
Magneto coupling in gear		0.003L	0.002L	0.004L
Magneto in cover		0.003L	0.001L	0.005L
Oil pump blade:				
In camshaft		0.003L	0.001L	0.005L
In oil pump (depth)		0.007L	0.005L	0.009L
Oil pump body to camshaft bushing		0.001L	Size	0.002L
Tachometer drive shaft in sleeve		0.0005T	Size	0.001T
Tachometer drive shaft assembly in cover		0.001L	0.0005L	0.0015L
S.A.E. tachometer shaft in drive shaft		0.009L	0.006L	0.012L
S.A.E. tachometer shaft tongue in drive shaft		0.014L	0.010L	0.018L
Tachometer drive shaft in drive plate (Series 2 including engine 371)		0.008L	0.004L	0.012L
Tachometer drive shaft in drive plate (Series 2 and 3 after and including engine 372)		0.006L	0.001L	0.011L
Tachometer drive plate in camshaft gear (Series 2 including engine 371)		0.0005T	0.0005L	0.0015T
Tachometer drive plate in camshaft (width) (Series 2 and 3 after and including engine 372)		0.018L	0.0146L	0.0216L
Intake valve in guide		0.002L	0.001L	0.003L
Exhaust valve in guide		0.0035L	0.0025L	0.0045L
Valve guide in cylinder		0.0017T	0.001T	0.0025T
Valve stem key in valve		0.005L	0.002L	0.008L
Valve in valve spring seat		0.006L	0.0035L	0.0085L
Valve tappet:				
In case		0.0012L	0.0005L	0.002L
In guide plate		0.0035L	0.002L	0.005L

* The letters L and T mean "loose" and "tight" by the amount shown.

All magnetos should be set at the correct positions before they are attached to the engine.

Before the magneto is attached, turn the crankshaft until the markings on it and the camshaft gear are in line as assembled. *Now turn the crankshaft in the opposite direction of rotation until the markings are off two and one-half teeth.* This puts the engine in approximately firing position for cylinder 1. With the magneto set as just described, it should be attached to the engine. Magneto points should break at approximately 27 deg. before top center (B.T.C.) on Series 2 engines, and approximately 22 deg. (B.T.C.) on Series 3, 4, and 5 engines. Both magnetos on the Series 5 engine fire at the same time, 22 deg. B.T.C.

To secure accurate timing, a 0.0015-in. feeler should be inserted between the points, the engine turned over slowly, and the exact opening position of the magneto points determined by a timing disk. Cellophane is a good substitute for a 0.0015-in. feeler. Final adjustment can be made to the magneto by rotating it on its slots until the exact timing position is reached. Tighten the nuts and put on the palnuts.

The exhaust and intake manifold can now be assembled to the block with the intake pipe inserted in the crankcase opening. Before the intake pipe is inserted in the crankcase opening, be sure that the aluminum flange and the rubber packing have been placed on the pipe. The cylinder heads have purposely not been assembled at this stage so that the copper asbestos gasket at the cylinder end of the pipe can be more easily placed. It is very important that this gasket be placed in the recess of the manifold which has been provided for it. Tighten the four brass nuts at the manifold to cylinder evenly, leading with the two inner nuts. Care should be exercised to see that the gasket is compressed evenly, and that the manifold fits the cylinder block tightly. If the copper-asbestos gasket is allowed to become dislocated, the manifold may become cracked when tightened.

After the nuts holding the manifold to the cylinder have been tightened and safetied, the two nuts holding the intake flange to the crankcase should be tightened. Be sure that the packing is properly in place. It is not necessary that the flange be drawn down against the crankcase; a firm tightening is all that is needed.

The cylinder heads may now be replaced, with care to see that all nuts are tightened evenly. As the head is made of comparatively soft aluminum, it should not be drawn excessively tight. Replace the palnuts.

Attach the ignition cable conduits next. Fasten the distributor block to the magneto. Mount the conduit brackets. Connect the ignition wires to the spark plugs.

With the Bendix-Scintilla magneto, it is best to trace each wire from the magneto to the spark plug to be sure that each goes to the cylinder corresponding to the number on the magneto. On the dual ignition engines the *right-hand magneto* (looking at the rear of the engine) *fires the top spark plugs*. In this installation it is particularly necessary to trace all wires from magneto to spark plug.

The assembly is completed by mounting the carburetor.

The running-in of any Continental engine requires about the same procedure as described on page 326.

Trouble Shooting

As all carburetor type internal-combustion engines work on the same principle, troubles that arise to prevent smooth and satisfactory operation

are very much the same, regardless of the make of the engine. There are differences between air-cooled and liquid-cooled engines, as far as places where trouble might be traced, such as air scoops or ducts and radiator stoppage; otherwise, they are very similar.

The following suggestions are from the Operator's Handbook of the Continental Motors Corp. and refer primarily to their low-powered, air-cooled engines. Other differences will be mentioned later.

Rough Running.—This means irregularity of impulses, such as are due to missing. Look to the following:

Air Scoop or Heater.—Be sure that a Vane-straightener type of scoop is being used, or a carburetor Vane heater.

Gasoline Supply: Quality.—Be sure that it is aviation gasoline of not less than 72 octane rating. Automobile gasoline, regardless of its octane rating, is not equivalent in any respect to *aviation* gasoline, and its use should be avoided. The S.A.E. 40 engines were designed to operate on aviation gasoline; any other will undoubtedly give poor performance and result in high maintenance cost.

Crankcase Oil Temperature.—This should be between 120 and 170°F. At any temperature below 120°F., the engine is likely to miss from insufficient heating of the intake mixture while passing through the crankcase manifolding. If the operating temperature of the oil is below 120°F., either of two methods is recommended to be used to correct for same:

1. By application of a suitable carburetor air intake heater. This will not appreciably increase the crankcase oil temperature, but will have the equivalent effect on the intake mixture, and will also prevent "icing" if that condition is experienced.

2. By lagging the crankcase with a heavy feltlike material. All portions of the crankcase should be covered except the rear. A coating of shellac or water glass over the lagging is very helpful in increasing its insulating capacity. The lagging may be held in place by safety wire and tape, or it may be glued to the crankcase. Care should be taken that no portion of the cylinders is covered.

Sticking Valves.—The valves of the A-40 are oiled only by external application. An oilcan filled with kerosene may be employed to wash the valve stems thoroughly. They should then be oiled with a very light grade of lubricant—never a heavy cylinder oil. It is desirable to oil the valve stems after every 4 or 5 hr. of operation. Frequent washing with kerosene helps keep the stems free from gum.

Spark Plugs.—All spark plugs should be tested frequently on a pressure-testing machine, their points reset to 0.015 in. and cleaned with a wire brush. Any plug shorting out below 140 lb. per sq. in. pressure should be discarded.

Caution. Do not leave mica plugs standing in gasoline.

Magneto Points.—Breaker point gap should be 0.012 in. on the Bosch and Scintilla, and 0.020 in. on the Bendix-Scintilla. Check the breaker point shaft for tightness of fit. The fiber bearing holding the points in alignment sometimes becomes worn and allows the breaker points to vary in gap while the engine is running, and also allows the shaft to "chatter."

Engine Firing Timing.—Cylinder 1 should fire on all A-40 engines numbered below and including 371, at 27 deg. before top dead center on the firing stroke. All other A-40 engines fire at 22 deg. before top dead center on the firing stroke.

Note: This varies with different makes of engines and with types of the same make.

Carburetor Float Level.—The float level in the A-40 carburetor should be ⅜ in. below the parting line. It is very seldom, indeed, that this adjustment needs any attention. The float level is set at the factory and should be good for the life of the engine.

Excessive Vibration. *Air Scoop or Heater.*—See page 309.

Mounting Bolts.—Be sure that all mounting bolts are tight, and that all "dough-nuts" are in place.

Propeller, Alignment and Balance.—Wooden propellers may be checked for static balance and alignment very easily and accurately, but it is almost impossible to have them checked for pitch balance. However, in order to check this possibility, it is suggested that you cross-check your propeller by trying it on another engine known to be delivering full power smoothly, or by trying another propeller, known to be in good condition, and comparing results. Propellers out of pitch balance become dynamically out of balance even though they are in perfect static balance.

Engine Firing Timing.—See page 309.

Engine Fails to "Rev" Up (No missing).

Tachometer.—Be sure that it is registering correctly.

Throttle Linkage.—Be sure that the throttle opens wide.

Propeller, Pitch Balance.—If the engine fails to "rev" up from seeming loss of power, it may be the propeller has increased its pitch due to weather exposure. All wooden propellers are subject to this type of error, and in many cases the change seems to take place within the space of one day's time. To the inexperienced operator, the effect on the performance of his engine does not seem to indicate that the propeller is at fault. Experience has shown that this condition is the cause of at least 90 per cent of the troubles with the A-40 engine "loss of power." Owing to the comparatively cheap manufacture of the propellers and instruments used in airplanes carrying the A-40 engine, these units cannot be expected to perform exactly alike, especially after a considerable number of hours of operation; it is advisable that these units be checked before attempting to locate troubles. If the engine does not "rev up," investigate thoroughly the possibility of the propeller or instruments, or a combination of both, as the cause. Considering the variations in propellers and tachometers, no concern should be felt if the engine turns between 2,100 and 2,300 r.p.m. on the ground, and between 2,350 and 2,600 r.p.m. in the air.

Gasoline Supply.—See page 309.

Spark Plugs.—See page 309.

Magneto Points.—See page 309 and 322.

Engine Firing Timing.—See page 309.

Carburetor Air Heater.—A carburetor air heater, properly installed and designed, will usually drop the r.p.m. approximately 100. However, if too much heat is admitted to the carburetor, the r.p.m. loss will be even greater. Further, if the intake opening in the heater is not of sufficient size, the r.p.m. drop will be considerably more.

Top Overhaul.—If these checks fail in the attempt to bring the r.p.m. of the engine up to normal, it is very likely in need of a top overhaul.

Engine Fails to "Take the Gun." *Idle Condition.*—See page 311. If the engine is not idling properly, it is likely that it will not "take the gun."

Crankcase Oil Temperature.—See page 309. A cold engine will not "take the gun."

Carburetor.—See page 322. It may be necessary to disassemble the carburetor and clean it thoroughly, blowing out all jets and lines. Any

adjustment necessary should be made by an experienced carburetor mechanic.

Engine Fails to Idle Properly. *Carburetor Idle Adjustments.*—Check the throttle arm setscrew and also the idle adjusting thumbscrew, making sure that both are properly adjusted. By turning *in* on the thumbscrew, the mixture is made leaner, and vice versa. Between two and three turns *out* on the thumbscrew is the approximate setting for most engines. It may be necessary to remove and clean the carburetor. The float level, within reasonable limits, will not affect the idle of the engine.

Primer Jets.—Be sure the primer jets do not leak either air or gasoline. If found to be leaking, it is likely the trouble will be found in the primer pump.

Intake Manifold Gaskets and Packings.—It is very easy to mislay the gasket on the cylinder end of the intake pipe. Be sure that this is in place. The rubber packings on the crankcase end of the intake manifold sometimes become hard from age and heat, and then fail to make an airtight seal. These gaskets should be examined and replaced if necessary, upon every disassembly of the engine. Also, check the carburetor to crankcase gaskets.

Magneto and Magneto Points.—See page 309. In addition to this check, it is suggested the charge of your magneto be tested at an authorized magneto service station.

Valve Clearances.—All valve clearances should be set at 0.015 in. cold. An uneven set of valve clearances will give rough and unsteady idling.

Spark Plugs.—See page 309.

Piston Rings.—If the piston rings are not seating properly or have not reached their proper seating, oil will pass the pistons while the engine is idling and collect on the cylinder heads instead of being burned. This will cause the engine to exhaust blue or white smoke when the throttle is opened, and the engine will probably be slow in taking the "gun," until it has cleared itself of the oil. If this condition is experienced on a comparatively new engine (less than 100 hr. of operation), the trouble will probably correct itself shortly and has been due to some irregular service during its early hours of operation. However, on some engines, and engines of more than 100 hr. operation, a replacement of piston rings should be made. Many factors are involved in piston ring wear but, if given the proper service, the piston rings should last easily 200 hr.

Flight Operation.—It is not unusual for any aircraft engine to "load up" when gliding into the landing field. This is due to the engine's cooling off and to its abnormal position. It is advisable to "hit the gun" frequently to keep the engine clear so that it may be used instantly if needed. Frequent "guns" are also beneficial to the engine as it keeps it from cooling too rapidly.

Engine Is Hard to Start.—In many cases of hard starting, it is found that the operator does not know how to start his engine. By this it is meant that he had never determined how to "set" his engine for the start: how many shots from the primer were necessary; how many times the engine should be pulled through before turning on the switch; when and if the engine is "loading," etc. It is impossible to give a solution to "how to start your engine" but it can easily be worked out for each individual engine by a little experimenting. Each time you start the engine, remember how many "shots" you gave it and how many times you turned it over before turning on the switch, etc. If you had trouble, vary the procedure slightly, trying one more or one less shot; in this way, you can no doubt find

out the procedure that will start your engine easily. After four "shots" and four revolutions of the propeller before turning on the switch, all turned as rapidly as possible, is a good place to start your experimenting. For a cold start, the throttle is usually about one-quarter open.

Gasoline Supply.—As before.

Spark Plugs.—As before.

Primer Jets.—In addition to this check, it is advisable to remove the jets and see if they are actually putting out a spray of gasoline.

Magneto and Magneto Points.—See page 309. In addition to this check, it may be necessary to clean the brushes.

General Condition.—If these checks fail to make the engine start easily, its condition will probably warrant a top overhaul. Successive weak fires indicate bad piston rings or leaky valves.

Engine Suddenly Loses "Revs" and Sputters in the Air—Then Recovers. This may be due to ice formation in the carburetor. Conditions of the atmosphere contributing to ice formation in the carburetor are too complicated and involved to attempt an explanation. However, ice is likely to form in the carburetor when the wet- and dry-bulb temperatures reach within 5°F. of each other with the outside dry-bulb temperature ranging from 10 to 45°F. Ice will form under favorable conditions very rapidly, and the engine will lose r.p.m. even to stopping completely. For the A-40 engine, the usual case is that the ice forms and then breaks away when the engine speed is reduced to about 1,200 r.p.m. The effect of this ice formation is the same as both closing the throttle and choking the engine. This condition can be avoided only by application of a suitable carburetor air intake heater.

Ignition Wiring.—Be sure all wiring is well insulated and solid.

Sticking Valves.—See page 309.

Vapor Lock.—Be sure that there are no high spots in the fuel lines where vaporized gasoline can collect and form a "pocket." Vapor locks are not common in the modern airplane with aviation gasoline, but occasionally they do happen.

Engine Has Sticky Piston Rings.—This may possibly be due to the oil used. Use a recommended oil of the proper grade for your particular engine. When in doubt as to the lubricant to be used, write direct to the manufacturer.

Obstruction in Front of Cylinders.—The air flow over the cylinders should not be obstructed in any way, as by extending the cowling in front of the cylinders or lagging any portion of them. The result of this condition is excessive heating, causing excessive wear, irregular wear, and sticking piston rings.

Gasoline Supply.—See page 309. Excessive heating of the pistons and cylinders, caused by the use of inferior gasoline, is a common cause for sticking piston rings.

Improper Climbing of the Airplane.—The cooling of an air-cooled engine is dependent mainly upon the air stream passing the engine while the airplane is in motion, and *not the air from the propeller blast.* Therefore, while the airplane is in flight, a speed sufficient to cool the engine should be maintained at all times. In other words, this means that "stall-climbing" should be avoided. The airplane's maximum rate of climb will give sufficient air flow to cool the engine, but the maximum rate of climb is not at the stalling point. A minimum forward speed must be maintained; below this minimum speed, the airplane simply "mushes" along, resulting in insufficient cooling

of the engine and sticking piston rings. Many students and private operators do not know the difference between a "stall-climb" and a "maximum rate of climb" and persist in using the former.

Ground Operation.—All aircraft engines should be thoroughly warmed up before a take-off, but this should be made with some discretion. Avoid full-throttle turnups on the ground as much as possible. It is necessary and desirable that the engine be given full throttle after it is warmed up to determine if it will "take the gun" and if the top r.p.m. is proper; however, a 10- to 15-sec. operation at this r.p.m. is sufficient. Warm-ups should be made at speeds approximating 600, 900, and 1,200 r.p.m. as the oil is gradually heated. Warm-ups requiring 30 to 45 min. should be avoided; about 15 min. is the desirable period. Warm-ups may be shortened by previously heating the oil, or by application of a crankcase lagging as described on page 309.

Long periods of idling also cause excessive heating of the cylinders and sticking piston rings. Long taxiing runs over soft earth should also be avoided if possible. Many times it is possible to use these runs in the warm-up period.

Oil Pump Fails to Pick Up Pressure on Starting.—The oil pump on the A-40 engine is of the Vane-type, and is self-priming only to the extent that it does not lose its prime from previous operations. The pump is so designed that the lower half of the body remains full of oil at all times—provided, of course, that there are no leaks. This is sufficient to prime the pump for immediate operation at any time. If the pump does not show pressure within 30 sec. after starting, there is evidently a leak at some point. First, be sure the gasket under the pump body is right and has not become hard or cracked from heat and age. Its thickness determines the clearance between the pump blade and housing, which is very important. Next, be sure that there is no leak in the pump housing. This may be checked by removing the housing and filling it with gasoline and inspecting for leaks. If a very light oil is used in warm weather, any small leak will allow the hot oil to drain out. In cold weather, the small amount of oil in the pump may be pumped out before a heavy cold oil can be picked up.

Care of Cylinders, Cylinder heads, and Cylinder Head Gaskets.—Once the cylinder head is firmly tightened to the cylinder of the engine, and with possibly a "check" tightening after the engine is warm, the cylinder head nuts should not be tightened again. Because of the difference in the expansion of the aluminum head and cast nickel-iron cylinder, the copper and aluminum cylinder head gaskets are forced to "creep" out with every heating and cooling of the engine. This "creeping" is naturally greater on the ends of the gasket than in the middle; it is not difficult to see that any tightening of the cylinder head after this "creeping" has begun will cause the head to be warped or bowed.

This "creeping" of the gaskets, if the head is not continually tightened, will not appreciably affect the cylinder head or cause a compression leak within 150 to 200 hr. of normal operation. After that approximate length of time, or even less in some instances, these gaskets should be renewed.

It is also important, when tightening the head, to remember that you are tightening a piece of comparatively soft aluminum, and it must not be tightened as though it were a piece of cast iron or steel. A reasonably firm tightness is sufficient if the nuts are tightened alternately, beginning from the center and alternating across the head, in such a manner that all nuts are taking effect evenly before any are drawn to their final tightness. This

even tightening of the cylinder head is very important. If these precautions are disregarded, a cylinder head may be cracked.

It is also necessary to remember the importance of "even tightening" when tightening the cylinder base nuts. Begin with the center nuts and alternate across the cylinder base, tightening each nut in the same manner as described for the cylinder head. If the first nut to be tightened on the cylinder base is drawn down tightly before the other nuts are taking equal effect, it is likely that the cylinder will become "cocked" by compression of the cylinder base gasket between the cylinder and crankcase, and will result in a marked overstress at this point when the other nuts are drawn down. The ultimate result of this error may be a cracked crankcase or a pulled-out stud.

Grinding of Valves.—When valves are to be ground, it is advisable always to install new valve guides before the reseating operation is started. This will ensure a square and true seating surface. Inasmuch as the top of the valve guide is approximately 1⅜ in. below the valve seat, any looseness of the pilot in the guide results in an appreciable error in the new seat.

Always hold the cutter flat to the valve seat face, and make sure that it is *held* perfectly centered to the complete circumference of the valve seat. Do not allow the cutter to spring off center because of cutting more metal on one side than on the other. This will produce a seat not perpendicular to the valve guide and result in a very short valve seat life.

Although not always absolutely necessary, it is desirable to use a seat cutter and valve refacer at every valve grinding. Both valve and valve seat should be refaced, or neither refaced; *never reface one without the other.*

If the valve and seat are refaced, the valve should then be ground in with a very fine compound. If neither has been refaced, a medium compound should first be used to remove the hard carbon particles, and then the final grinding accomplished with a very fine compound. It is also very important that only a *slight* pressure be used on the valve while grinding. In no case should you use an oscillating or rotating grinder. "Lift" the valve frequently and "tap" in the seat. A hard grinding motion will not give the smooth accurate seat desired, but result in a grooved uneven surface.

OTHER CONTINENTAL ENGINES

The A-50, Series 4 and 5, are four-cylinder, horizontally opposed, four-cycle, overhead-valve, air-cooled engines; they have a rating of 50 hp. at 1,900 r.p.m.; cruising r.p.m., 1,700 to 1,850.

Bore	3⅞
Displacement, cu. in.	171
Compression ratio	5.4 to 1
Firing order	1-3-2-4
Oil pressure, lb	30–35
Oil sump capacity, qt	4
Oil temperature, max	215°F.
Fuel	65 to 72 octave, or better
Ignition	Bendix-Scintilla, single or dual
Carburetor	Stromberg NA-S3
Plugs	Champion M-3-1

A-65, Series 1 and 3, are the same as the A-50, Series 4 and 5, *except* the following:

Series 1	65 hp. at 2,350 r.p.m.
Series 3	65 hp. at 2,300 r.p.m.
Compression ratio	6.3 to 1
Fuel	72 octane, or better
Carburetor	Stromberg Na-S3A1

A-75, Series 3, are the same as A-65 *except* that they have a rating of 75 hp. at 2,650 r.p.m.; cruising r.p.m., 2,350 to 2,450.

All these run counterclockwise, facing the propeller end. These engines are shown in Fig. 2, which gives the outline dimensions for mounting. Continental also builds a radial engine similar in power to the Kinner and Warner.

Crankcase.—The crankcase is a two-piece heat-treated aluminum alloy casting bolted together at the vertical lengthwise plane through the crank and camshafts. There are rigid transverse webs to hold the three main bearings and the three camshaft journals. A specially designed oil seal prevents oil leakage at the propeller. Large tappet guides are formed in the crankcase in a plane below and parallel to the cylinders. Cast-in lengthwise tubes lead oil pressure to the tappet guides, camshaft, and main bearings. Circumferential stiffening ribs under the cylinder pads give additional strength and stiffness to the cylinder hold-down bosses. Four engine mount bosses for ⅜-in. bolts are provided at the rear of the crankcase as in radial engines. To the rear and on the bottom of the crankcase there is a large flange for supporting the integral oil sump.

Cylinders.—Heat-treated, aluminum alloy cylinder heads are screwed and shrunk to forged steel barrels. Closely spaced cooling fins are provided on barrels and cylinder heads to provide ample and efficient radiation surface. Cylinder bores are ground to mirror finish and held within extremely close limits. The A-50 and A-65 engines have aluminum bronze spark-plug inserts and valve seats shrunk into the cylinder heads; the A-75 has austenitic steel exhaust valve seats and aluminum bronze spark-plug inserts. Rocker boxes are cast integral with the heads and provided with oil-sealed covers. Drains are provided on each cylinder for the scavenging of the rocker boxes.

Pistons.—All models have heat-treated aluminum alloy Lo-Ex permanent mold pistons. The A-75 pistons are internally ribbed for greater strength and heat dissipation. Two compression rings and two oil scraper rings, one of the latter being below the piston pin, are provided on the A-50 and A-65 piston; the A-75 piston has a third compression ring above the piston pin, thus making five rings on the A-75 piston. The A-50 pistons have a compression ratio of 5.4 to 1; the A-65 and A-75 pistons have a compression ratio of 6.3 to 1.

Connecting Rods.—The connecting rods are of conventional design and of heat-treated alloyed steel forgings. The split big end bearing is the replaceable thin steel back shell type, copper-lead lined. At the piston pin end is a pressed-in bronze bushing. The connecting rods used in the A-75 have specially drilled oil holes for extra oiling of all cylinder bores.

Crankshaft.—The alloy steel, one-piece, four-throw crankshaft is supported by three steel-backed copper-lead lined main bearings. The crankshaft is drilled for lightness and to provide pressure for lubrication of crankpin journals. The crankshaft end clearance is fixed by the front main bearing setting between the forward crank cheek and a collar machined on the shaft. This construction provides a thrust bearing for tractor or pusher installation.

Camshaft.—The cast-steel camshaft has hardened cams and journals. There are six cam lobes, three journals, and an overhung eccentric at the forward end for operating a fuel pump. The exhaust cams are adjacent to the journals. The intake cams are common to opposing cylinders. At the rear end is a flange for the attachment of a gear by cap screws.

Valve Gear.—Hydraulic tappets fit aluminum alloy guides machined in the crankcase so sealed as positively to prevent oil leakage. The tappets are drilled in such a manner that an oil passage is provided from them to the push rods, rocker arm bearings, and rocker end. The push rods are made of light steel tubing with pressed-in ball ends, hardened and ground, and drilled their entire length to provide an oil passage to the overhead mechanism. The push rod is fully enclosed, and the outer end fits into a socket in the rear of the valve rocker. The rocker acts directly on the valve through a specially designed "foot" so constructed as to prevent side thrust on the valve stem. Splash keeps valve guides oiled at all times. Oil is returned to the crankcase by the push rod housing.

Accessory Case.—The accessory gear case casting at the antipropeller end of the engine provides support for ignition units, oil pump, and tachometer drive. (Provisions are made for a starter on special models.) The gear case has the oil suction tube, the oil drain, oil screen, the pressure relief valve, and oil lines to match the several crankcase oil lines. The entire assembly with accessories is removable as a unit.

Intake and Exhaust System.—Carburetion is supplied by an updraft Stromberg NA-S3 (A-50), NA-S3A1 (A-65 and A-75), carburetor connected to an "X" manifold. This manifold is attached by two studs to the underside of the crankcase midway between cylinders. Steel intake pipes connect this manifold to each of the four intake ports. A primer connection is provided at each of the cylinders to facilitate cold-weather starting. There is also a primer connection just above the carburetor and below the manifold "X."

Lubrication.—The A-50, A-65, and A-75 engines are essentially dry sump engines, but to minimize installation problems and to reduce the number of external oil lines, an integral sump has been attached directly to the crankcase. Oil is drawn from the oil tank through a suction tube extending down into the tank and delivered under pressure to a filter from which it goes through drilled passages in the accessory and main cases to all drive bearings, through the crankshaft, and to the crankpins. On the A-75 models, oil is ejected from each connecting rod cap to the adjacent cylinder bore, thus ensuring adequate lubrication under the most severe conditions.

Engine oil from the pressure pump is carried through drilled passages in the crankcase to the hydraulic tappets. After entering the tappets, it travels out through the overhead mechanism through hollow push rods, and is spilled over the rocker arm and valve mechanism. As it drains away, it thoroughly oils the valve stems and valve guides. The oil is returned to the crankcase by way of the push rod housings, and drains back into the integral oil sump through the large opening provided for this purpose. In the A-50, A-65, and A-75 models, cylinder walls and piston pins are lubricated by a spray, while the system discussed in the preceding paragraph is provided for supplementary lubrication in the A-75. Excess oil in the crankcase is returned by gravity to the oil sump. The pressure relief valve is set to give approximately 33 lb. of pressure at speeds of from 1,900 to 2,650 r.p.m.

Testing.—Every engine is run 3½ to 5 hr. of which 1 hr. is at full throttle with propeller load. It is then completely disassembled and inspected. After reassembling, it is given an additional ½-hr. check run at full load, full throttle. The thoroughness employed in testing production engines is a safeguard to Continental quality.

Installing Series A-50, A-65, and A-75.—The engine should be bolted to the plane at the four mounting pads, using ⅜-in. bolts of good steel. Spool

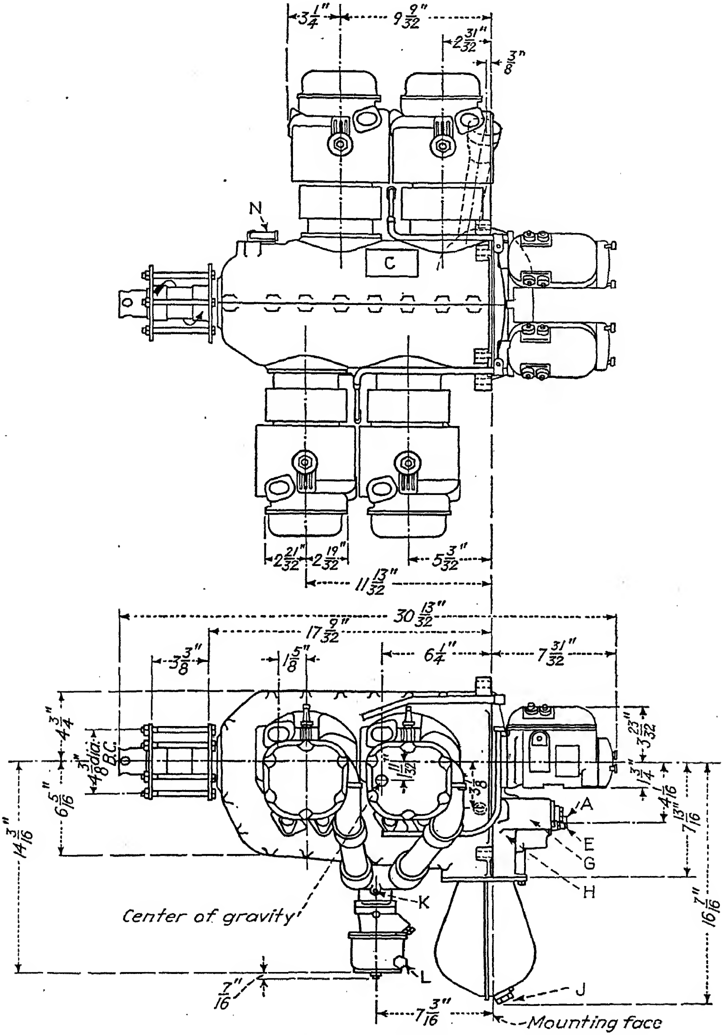


Fig. 4.—Mounting dimensions of model A-75, Series 3.

or cone rubber mounting washers should be used to prevent metal-to-metal contact between the engine and frame. This will reduce both noise and

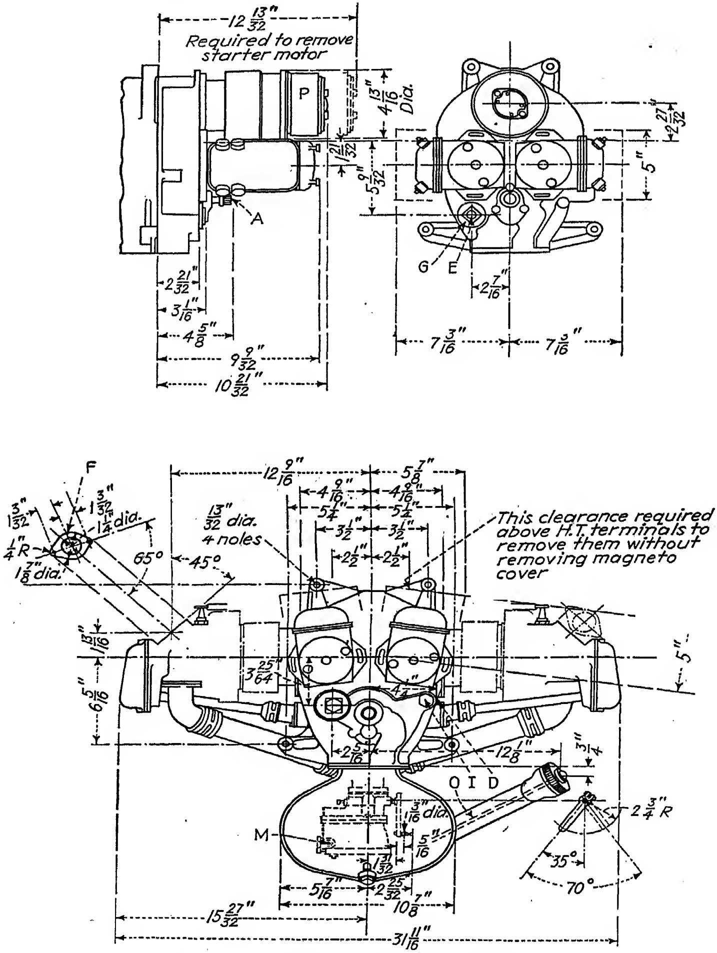


Fig. 5.—Other dimensions of A-75, Series 3.

vibration. The mounting bolts should be tightened from time to time as the rubber washers take a permanent set.

Fuel Supply.—The fuel tank should be placed so that the head of fuel is never less than 2 in. in the steepest climb or more than 90 in. in a steep glide. The primer may be connected at the manifold riser above the carburetor or at the intake ports of each cylinder. For temperatures above 20°F., the manifold position should give easy starting. At lower temperatures, the port position is best.

A carburetor entrance duct with a valve to regulate air temperature is standard equipment with each new engine. This duct should be extended forward if necessary, so that impact air will be supplied to the carburetor. A 2-in. tube connection at the rear of the carburetor entrance valve should be connected to a source of heated air, so that air at 100°F. will be available to insure vaporization of the fuel.

Table 2.—Fuel Consumption, A-50

Engine r.p.m.	Gal. per hr.										
2,100	5.57										
2,050	4.71	5.49									
2,000	4.31	3.60	5.42								
1,950	4.00	4.20	4.50	5.34							
1,900	3.75	3.91	4.11	4.42	5.26						
1,850	3.53	3.67	3.82	4.04	4.26	5.18					
1,800	3.35	3.47	3.59	3.75	3.96	4.28	5.10				
1,750	3.17	3.28	3.39	3.52	3.66	3.89	4.22	5.02			
1,700	3.02	3.11	3.21	3.32	3.43	3.59	3.81	4.13	4.93		
1,650	2.88	2.96	3.05	3.14	3.24	3.35	3.51	3.73	4.08	4.85	
1,600	2.75	2.81	2.89	2.98	3.07	3.17	3.29	3.45	3.65	3.97	4.77
1,550	2.62	2.68	2.75	2.83	2.91	3.00	3.10	3.23	3.38	3.57	3.90
1,500	2.50	2.55	2.62	2.69	2.77	2.85	2.94	3.04	3.16	3.29	3.50
1,450	2.38	2.43	2.49	2.56	2.63	2.71	2.79	2.88	2.99	3.08	3.22
1,400	2.27	2.32	2.37	2.44	2.50	2.58	2.66	2.75	2.83	2.93	3.02

Fuel Consumption.—The fuel consumption to be expected under various operating conditions is given in Tables 2 and 3. The first table pertains to the operation of the A-50; the second, to the operation of the A-65 and A-75. The values shown are average; atmospheric conditions, engine condition, etc., may be expected to vary these figures throughout the range ±8 per cent.

Instructions.—Assume that you are checking up on the gasoline consumption of an A-50 engine. From the left-hand column of Table 2, choose the full-throttle level flight r.p.m. The figure then on the extreme right should give the gasoline consumption. All values under the full-throttle consumption represent the cruising consumption at speeds indicated on the extreme left.

Example.—A-50 full-throttle level flight r.p.m. 2,050; gasoline consumption 5.49 gal. per hr. Cruising at 1,750 r.p.m.; consumption 3.28 gal. per hr. Cruising at 1,800 r.p.m.; consumption 3.47 gal. per hr. The different values show the effect of speed in all cases. If, for example, the engines use 5.34 gal. at 1,950 r.p.m., reducing the speed to 1,800 r.p.m. should cut fuel consumption to 3.75 gal. The consumption will of course vary with the plane, the load, and other conditions.

As a rule, these engines will need only the engine check every 100 hr., and a major overhaul every 500 to 600 hr. The operating time before a major overhaul is, of course, greatly dependent upon the care the engine has had

and the type of service to which it has been subjected. Experience has shown that operating periods of from 500 to 600 hr. between major overhauls can easily be reached by normal operation and maintenance.

Table 3.—Fuel Consumption, A-65 and A-75

Engine r.p.m.	Gal. per hr.														
2,850	6.52														
2,800	5.87	6.46													
2,750	5.43	5.84	6.42												
2,700	5.26	5.51	5.83	6.37											
2,650	5.02	5.20	5.49	5.74	6.31										
2,600	4.81	4.98	5.20	5.35	5.75	6.25									
2,550	4.72	4.77	4.94	5.14	5.41	5.58	6.18								
2,500	4.44	4.57	4.72	4.90	5.13	5.30	5.54	6.12							
2,450	4.28	4.40	4.53	4.67	4.87	5.01	5.20	5.44	6.04						
2,400	4.12	4.23	4.35	4.49	4.64	4.76	4.92	5.09	5.38	5.96					
2,350	3.97	4.06	4.18	4.31	4.44	4.53	4.68	4.81	5.04	5.38	5.98				
2,300	3.83	3.91	4.02	4.14	4.25	4.35	4.48	4.58	4.77	4.95	5.30	5.80			
2,250	3.68	3.76	3.87	3.97	4.10	4.17	4.29	4.39	4.51	4.68	4.94	5.10	5.71		
2,200	3.55	3.60	3.72	3.81	3.92	3.99	4.10	4.19	4.33	4.44	4.61	4.77	5.02	5.62	
2,150	3.40	3.47	3.58	3.66	3.76	3.83	3.94	4.03	4.11	4.23	4.38	4.50	4.68	4.89	5.53
2,100	3.27	3.33	3.44	3.51	3.60	3.67	3.78	3.85	3.96	4.06	4.17	4.27	4.42	4.58	4.85
2,050	3.14	3.20	3.29	3.37	3.46	3.52	3.61	3.68	3.78	3.87	3.97	4.07	4.18	4.32	4.53
2,000	3.01	3.07	3.16	3.23	3.31	3.37	3.47	3.53	3.61	3.70	3.80	3.88	3.98	4.10	4.28
1,950	2.88	2.94	3.02	3.09	3.17	3.23	3.31	3.38	3.45	3.53	3.61	3.69	3.79	3.90	4.06
1,900	2.76	2.82	2.89	2.95	3.03	3.09	3.17	3.23	3.30	3.37	3.46	3.53	3.61	3.71	3.87
1,850	2.62	2.70	2.76	2.81	2.88	2.95	3.02	3.08	3.15	3.22	3.29	3.37	3.45	3.53	3.67

No general top overhaul is recommended but, if a valve begins to leak or the engine performance falls off, the cylinder causing the trouble should be located and removed and the condition corrected. If the engine behavior indicates that special maintenance is needed before a major overhaul, it is well to make a careful check of all controls, spark plugs, mixture and spark setting, ignition breaker points, fuel system, and propeller to make sure that poor functioning of one of these items is not affecting the performance.

Engine Check (Every 100 Hr.)—An engine check is done without removing the engine from the airplane, as follows:

Check all engine mounting bolts to see that they are tight. If the engine has a rubber mounting, the bolts at the engine mounting lugs should be tightened firmly but should not be drawn down too solidly.

Check the propeller hub bolts for tightness and check the propeller for track, making corrections if necessary. The propeller should track within ⅛ in.

Inspect for oil leaks. Any undue amount of oil appearing at any point on the engine is an indication of trouble and should be thoroughly investigated.

Inspect the gasoline and oil lines for breaks or loose connections.

Check the control linkages for undue wear, missing cotter-pins, and see that full travel of all controls is obtained.

Check the altitude control adjustment, making sure that positive and full movement of the control arm on the carburetor is obtained.

Remove and clean the scavenge oil stainer located in the accessory case below and back of cylinder 2. Clean the gasoline sediment bulb.

Check the spark plugs; clean and reset the points to 0.015 in.

Check the ignition wires for breaks or bróken insulation, and clean the terminals going into the magneto.

Inspect the ignition breaker points and reset them according to the manufacturer's specifications.

Check the engine thoroughly for loose bolts and nuts, and make sure that all palnuts are in the place.

Wash the engine thoroughly with a cleaning fluid, *preferably not inflammable* to avoid fire hazard.

Inspecting the Engine.[1] *Crankshaft.*—Clean the crankshaft oil pressure holes thoroughly with clean gasoline, and blow them out with air. Inspect the journals for scuffing and check the journal fillets for cracks.

Bearings.—Inspect the main and connecting rod bearings for cracks or checks. If cracks or checks are visible, renew both halves of the bearing. If it is necessary to replace any main or connecting rod bushings, it may be done by simply pressing in new bushings with the fingers. Both the large end connecting rod bushings are identical except in the A-75 where the cap end bushings are drilled for an oil passage. Check the bronze piston pin bushings for signs of scuffing or overheating; if they appear burned or rough, make replacement.

Pistons, Piston Pins, Piston Rings.—Remove all rings, clean carbon from ring grooves and heads of pistons. Do not polish the contact surfaces of the piston. If slight score marks are visible, stone lightly with a fine Pike stone. Stone only enough to remove the metal which has piled up, as deep scratches cannot be removed. If scoring is heavy, the pistons must be replaced. Inspect the pin bosses. If worn, the piston must be replaced. Check the piston ring grooves for wear. If worn beyond service tolerances, the piston must be replaced. *Piston rings should always be replaced at the time of a major overhaul.*

Cylinders.—Check for scores. Very light scores can be removed with crocus cloth. If the cylinders have heavy scores, they should be replaced. Check the valve seat inserts; if badly burned, replace. (Valve seat replacements can be made only with special equipment; if necessary, they should be returned to the factory or to a shop well equipped for this type of work. Cylinder barrels can also be replaced by the factory.) Check the valve guides; if worn beyond the tolerances given in Tables 4 and 5, they should be replaced. Check the cylinder heads thoroughly for cracks and deep scratches. Any dents or deep scratches should be stoned out to prevent failure.

Valves and Valve Springs.—Recut all valve seats; reface all valves, replacing those that we do not clean up on valve-refacing machines. Regrind all valves. Clean all gum from the valve stems but do not polish, as that will remove the hard glaze which is desirable. Check all valve springs for wear, tension, and breakage.

Camshafts.—Inspect the lobes on the cam; if scuffed, stone lightly. Inspect cam bearings for scratches. If the cam lobes are scuffed, the cam followers are probably also scuffed and will have to be stoned lightly on the inner end.

Crankcases.—Check the crankcase thoroughly for fatigue cracks. Clean it with gasoline, blowing out all oil lines.

Pressure Relief Valve.—Clean thoroughly and reinstall. The plunger should work freely in its cage without sticking.

Oil Pump.—Check the oil pump gears; if they are nicked or scratched, stone lightly. Remove all burrs. If the gears are badly dented or worn, they should be replaced.

Tachometer Drive and Crankshaft Oil Seal.—It is always best to replace all gaskets and packings at the time of a major overhaul.

[1] See p. 325 for service tolerances.

Hydraulic Tappets.—Inspect the tappet mechanism thoroughly for burrs and gum formation. The tappet is a very rugged mechanism and no damage is likely to occur to it if handled with care. Care should be exercised to see that it is not dropped or nicked because of contact with other metallic objects. The tappet is composed of only four parts which can be disassembled: the cap, cylinder, piston, and guide. The tappets should be washed thoroughly and the piston should work freely in the cylinder. If either the piston or the cylinder is damaged, both parts must be replaced. The guide, or actually, the cam follower, and the cup are supplied as units separate from the piston and cylinder; however, all may be obtained as a complete hydraulic tappet assembly. A wire may be inserted in the tube at the end of the cylinder to relieve the ball check so that the piston can be moved freely, thereby allowing a better examination of the unit.

Magneto.—Inspect the points and true them up if pits are visible, making sure that the points are flat against each other. Oil only according to the magneto instruction book. Inspect the wiring harness. If wires are damaged, they should be replaced. See that all wires are well anchored and that positive contact is made. The magnetos of the type used on these engines do not have any set point gap clearance. When the magneto is correctly timed internally, the point gap is automatically set.

Carburetor.—The carburetor needs practically no attention aside from draining the float bowl of water, which can be done by removing the ¼ pipe plug in the bottom of the float chamber. For reconditioning the carburetor, special instructions should be obtained from the manufacturer.

Gaskets and Packings.—It is always best to use new gaskets and packings throughout, when reassembling an engine.

Assembling the Engine.—A minimum amount of effort and skill is required both in assembling and disassembling the A-50, A-65, and A-75 engines. Many of the clearances, formerly requiring much attention, are now built into the engines and can be disregarded by the mechanic. Connecting rods and main bearings are not to be reamed or fitted in any way. Crankshaft end play is determined by the length of the front main bearings; if the clearance is excessive, replace the bearing.

All parts should be thoroughly cleaned before the assembling is started. Serious injury to the engine can often be traced to dirt and parts not thoroughly cleaned during the overhaul.

The cylinders should first be cleaned, and the valves, springs, etc., assembled. After the valves are ground, the ports should be filled with gasoline and tested for leaks. If gasoline leaks past the valve within 15 sec., the valve should be reground. Be sure all valve-grinding compound is removed from the valve stem and guide, as well as the cylinder bore. After oiling the valve stems thoroughly and wiping the guides clean, assemble the valve, washers, springs, and locks to the cylinder. Wipe the cylinder bore clean and set aside until assembly has progressed further on the engine crankcase.

Snap the connecting rod bushings in place and reassemble the connecting rods to the crankshaft in such a way that all connecting rod numbers will be pointing up when the shaft is reassembled to the engine. All connecting rods are, of course, assembled in their respective positions.

Snap in all main bearings in their respective positions and, working with each half of the crankcase separately, insert the cam followers. It is suggested that a rubber band be drawn around each pair while outside of the crankcase. This is merely to hold the followers in place while the two halves of the crankcase are being assembled.

With cylinders 1–3 of the crankcase laid with bearings up, set the crankshaft in place. Counting from the rear of the engine, connecting rods 1 and 3 should be placed through the cylinder openings. Also, lay the camshaft in position. Side 2–4 of the crankcase may now be lifted on, and the two halves bolted together. No gasket is used between the two halves of the crankcase, but in order to prevent a slight oil seepage, each contact surface should be covered with a thin coat of Fostoria Titeseal. Before applying the Fostoria, however, be sure to see that all contact surfaces are clean.

The cam gear is next attached to the cam and should be placed in such a manner that its marking meshes with the markings on the crankshaft gear. The spacing of the screws holding the cam gear to the cam is such that the gear can be placed on in only one position. Safety-wire the cam cap screws after they have been firmly tightened.

The hydraulic tappets are now ready to be installed. First, the mechanism should be washed thoroughly and oiled with a thin coat of oil. Insert the piston (hydraulic) in its cylinder and make sure that it is functioning smoothly. A small wire will have to be inserted in the tube at the lower end of the cylinder to relieve the ball check before the piston will go all the way to the bottom. After it is determined that the mechanism is in good order and free from any dirt or foreign substance, and with the ball check working freely, submerge the tube of the hydraulic unit in a pan of clean oil. By pumping the piston with the thumb, fill the tappet with oil until the spring action ceases. The tappet should be installed "pumped up," as just described. The tappets may be simply inserted to their housings, but they should be in their respective order.

Place the small cup for the foot of the push rod on top of the tappet and immediately install the push rod housing flanges. A new gasket should be used at the push rod housing flange. In order to make a perfect oil-tight seal, a small amount of Fostoria should be applied to the push rod housing gasket before it is installed. The push rod housing flange has a small lip that will securely hold the push rod housing cup in its correct position.

After new rings have been installed on the pistons, the assembly may be fitted to its respective connecting rod with the numbered side facing the propeller end of the crankshaft. As the pin is tapped into position, the piston must be carefully supported to avoid its coming in contact with other metallic surfaces. Be sure that all piston pin plugs remain in place.

The push rod housings are a part of the cylinder assembly, and must be installed as such. Before any cylinder is reassembled to the crankcase, the crankshaft should be turned until its piston is brought to the outer end of the stroke. The cylinder should be carefully wiped off with a clean cloth and both cylinder and piston thoroughly oiled. On all engines a new rubber cylinder base packing should be used between the cylinder base flange and the crankcase. In order to afford a positive seal against oil leakage, use a small amount of Fostoria Titeseal around the cylinder flange on the flat surface that contacts the crankcase.

Before the cylinders are installed, new push rod housing rubber hose should be installed on the housing and pushed back up toward the cylinder head for clearance while the remainder of the assembly is taking place. With the cylinder held firmly against the body to steady it, this unit is placed over the piston. After the rings have been rotated until the gaps are evenly spaced about the piston, they are then compressed until the cylinder is over them. As soon as the cylinder is in place, several of the cylinder base nuts should be drawn down before another cylinder is started.

Following this same procedure, assemble all four cylinders to the crankcase. Tighten all cylinder base nuts firmly but not excessively.

After the cylinders are in place, the rubber hose connections on the push rod housing can be slipped down in place and tightened with the metal hose clamp.

New hose connections should be used on all intake pipes. Attach the carburetor intake manifold; by manipulation of the rubber hose, the intake pipes can be installed. Attach and safety the carburetor as well as place safety nuts on all crankcase and cylinder nuts. Do not tighten the intake manifold studs too much.

The oil pump is reassembled into the accessory case, as well as is the tachometer drive unit. As the tachometer drive shaft goes through the rawhide oil seal, make sure that the packing remains in position, and is not pushed out of place by the drive shaft. It may be advisable to use a $\frac{7}{16}$-in. rod to lead the shaft through the packing so that it will not be pushed out of position. Be sure to safety the nuts holding the oil pump plate to the accessory case.

By properly meshing the oil pump drive in the cam gear, the accessory case may be attached to the engine. Tighten all nuts firmly and safety them.

With the engine rotated to such a position that the intake and exhaust valves are closed on any one particular cylinder, the push rods and rocker arms may easily be installed. Insert the push rods into their respective housings and, as the rocker arm is held in place, push in the rocker arm shaft.

It is seldom necessary to check the valve tappet clearances, as they are built into the engine. No method is provided for adjusting clearances. Tappets will function properly with "dry" clearances ranging from 0.030 to 0.110 in. At the factory, clearances are set at from 0.050 to 0.080 in.

If, however, it is desired to check the clearances, a screw-driver blade should be inserted between the valve stem and rocker arm in such a manner that the valve is held partly open. This should be done, of course, with the cam in such a position that the valve would be closed. Leave the screw driver in place for 10 or 15 min. to allow all oil and air to leak out of the tappets, thus leaving them perfectly "flat." Remove the screw driver and, while keeping considerable pressure on the push rod end of the rocker arm (taking up all spring tension), check the clearance between the rocker arm and valve stem. This clearance should be between 0.030 and 0.110 in.

Before starting the engine after the tappet clearance check, the tappet should be removed and pumped up as previously described. It may require 2 or 3 hr. of operation before the tappet pumps up automatically, and considerable damage can be done to the engine.

The engine is now ready for the magneto installation. Rotate the magneto until the mark on the gear which can be seen through the inspection window is in line with the small pointer, which is also visible. This places the magneto in firing position for cylinder 1. Rotate the engine in a counterclockwise direction until the firing stroke of cylinder 1 is reached.

The A-50 and A-65 engines are supplied in dual- and single-ignition models; the A-75 is supplied only in the dual-ignition model. In all instances, *the right magneto*, facing the accessory case from the rear of the engine, *fires the top plugs;* the left magneto fires the lower plugs.

For the Single-magneto A50-4 Engine.—Set the engine at 28 deg. before top dead center on the firing stroke. This puts the engine in firing position for cylinder 1. The magneto coupling is then inserted into the serrated magneto

drive gear without turning the motor or magneto. The mounting studs may be tightened enough to hold the magneto in position against the accessory

Table 4.—Index of Fits of Main Parts of Continental A-50, Series 4 and 5, A-65, Series 1 and 3, and A-75, Series 3

	Fit Numbers
Piston, rings and pins	1–15
Connecting rod	16
Crankshaft bearings	17–18
Valves and guides	19–21
Camshaft	22–23
Valve tappet	24
Rocker shaft	25–26
Oil pump	27–30
Valve springs	31–32
Oil relief valve	33
Crankshaft and cylinder wear	34–36

Table 5.—Fits, Continental A-50, Series 4 and 5, A-65, Series 1 and 3, and A-75, Series 3

Fit No.	Main parts	Nominal size	Desired	Min.	Max.	Max. allowable, after use
1	Piston in cylinder (skirt)	3 7/8	0.014	0.014	0.017	0.020
2	Top piston ring in groove (A-50)	3/32	0.0035	0.0025	0.004	0.008
3	Top piston ring in groove (A-65, A-75)	3/32	0.006	0.005	0.0065	0.008
4	2nd piston ring in groove (A-50)	3/32	0.003	0.002	0.0035	0.0055
5	2nd piston ring in groove (A-65, A-75)	3/32	0.0035	0.0025	0.004	0.0055
6	3d and 4th piston ring in groove (A-50)	3/32	0.002	0.001	0.0025	0.0055
7	3d piston ring in groove (A-65, A-75)	3/32	0.0035	0.0025	0.004	0.0055
8	4th piston ring in groove (A-65)	3/32	0.002	0.001	0.0025	0.0055
9	4th piston ring in groove (A-75)	3/32	0.0035	0.0025	0.004	0.0055
10	5th piston ring in groove (A-75)	3/32	0.002	0.001	0.0025	0.0055
11	Piston ring gap—all rings	0.012	0.012	0.007	0.017	0.025
12	Piston pin in connecting rod bushing	55/64	0.0014	0.0013	0.002	0.003
13	Piston pin in piston	55/64	0.0004	0.0001	0.0007	0.0015
14	Piston pin and plug in cylinder	3 7/8	0.025	0.010	0.042	0.070
15	Plug in piston pin	5/8	0.001	Size	0.002	0.004
16	Connecting rod bearing to shaft	1 15/16	0.002	0.0008	0.0028	0.004
17	Crankshaft in front main bearing (end clearance)	3 1/4	0.011	0.005	0.017	0.020
18	Crankshaft in main bearings	1 7/8	0.003	0.0015	0.004	0.0055
19	Exhaust valve in guide	11/32	0.0037	0.0027	0.0047	0.006
20	Intake valve in guide	11/32	0.002	0.001	0.003	0.005
21	Valve guide in cylinder head	17/32	0.002	0.001	0.003	0.005
22	Camshaft journals in crankcase	1 3/8	0.002	0.001	0.003	0.005
23	Camshaft rear journal in crankcase (end clearance)	1 1/32	0.006	0.004	0.008	0.010
24	Valve tappet in crankcase	23/32	0.0013	0.0005	0.002	0.0031
25	Rocker shaft in rocker bearing	39/64	0.0016	0.0011	0.0021	0.004
26	Rocker shaft in cylinder head	39/64	0.0007	0.0002	0.0017	0.003
27	Oil pump drive shaft in cover	9/16	0.002	0.0015	0.003	0.005
28	Oil pump driven shaft in cover	9/16	0.002	0.0015	0.003	0.005
29	Oil pump drive shaft in plate	9/16	0.002	0.0015	0.003	0.005
30	Oil pump gears (end clearance)	3/8	0.003	0.002	0.005	0.010
31	Inner valve spring (compressed to 55/64)	.....	33*	31 1/2*	34 1/2*	29*
32	Outer valve spring (compressed to 61/64)	.....	61*	59*	63*	55*
33	Oil relief valve spring (compressed to 1 9/16)	.....	5 1/4*	5 1/8*	5 3/8*	5*
34	Crankpins out of round	.....	......	......	......	0.0015
35	Cylinder bores out of round	.....	......	......	......	0.0025
36	Crankshaft runout (center main)	.....	......	......	......	0.005

* Pounds pressure needed to compress springs to desired length.

The magneto is now approximately in firing position. Before checking the exact breaker opening position, the magneto should be rotated in a counterclockwise direction by tapping the mounting flange until it is near

the end of the travel permitted by the slots. The crankshaft may then be turned backward a little, and brought slowly up to firing position to take the backlash out of the driving gear train.

A 0.0015-in. feeler should be inserted between the breaker points, and each magneto flange tapped in a clockwise direction until the exact point of release is reached. Cellophane is a very good substitute if a 0.0015-in. feeler is not available. After tightening the mounting nuts, check the timing by backing up the crankshaft and turning it slowly forward at short intervals to determine if the feeler is released the instant the disk reaches the 28-deg. mark. *All traces of cellophane must be removed before replacing the breaker cover.*

For the Dual-ignition A50-5 Engine.—The procedure as just described is repeated for each magneto, *except that for the left magneto* (firing lower plugs), the crankshaft location for attaching the magnetos should be 28 deg. before top dead center, and 25 deg. before top dead center for the right magneto (firing upper plugs). *The magnetos on the dual-ignition model rotate in opposite direction to that of the single-ignition model;* this should be borne in mind in following these instructions.

For the Single-ignition A-65-1 Engine.—The same procedure as described for the A50-4 engine is followed, *except that the magneto timing should be* 30 deg. *before top dead center.*

For the Dual-ignition A65-3 Engine.—The procedure described above for the A50-5 engine is followed exactly with the exception that the timings of both magnetos should be 30 deg. before top dead center.

For the Dual-ignition A75-3 Engine.—The procedure described for the A50-5 engine should be followed exactly, with the exception that the *left magneto (firing lower plugs)* should be set at 32 deg. before top dead center; the right magneto (firing top plugs) should be set at 30 deg. before top dead center.

Tighten and safety the magneto flange nuts. Install all valve rocker covers and safety. Check over the entire engine and be sure that palnuts are used on all exposed nuts.

The engine is now ready to be reinstalled.

Engine Run-in.—It is very important that an engine be carefully run in after a complete or top overhaul. The length of time necessary for this depends upon the number of new parts installed during the overhaul and the facilities available for the running-in process. A *flying propeller* does not cool the engine properly if the airplane is not in flight, and any continued full-throttle operation should be avoided on the run-in unless a special *cooling propeller* is used. It is also advisable to have a thermocouple attached at the base of the spark plugs and not allow the cylinder head temperature to exceed 500°F.

When new pistons or bearings are installed, at least 5 hr. of run-in time should be put on the engine. New rings may be broken in sufficiently for flight in possibly 3 to 4 hr.

The engine should be filled with a light grade of oil and run at approximately 800 r.p.m. until the oil is thoroughly warm. Then at intervals of 15 to 20 min., the speed should be increased by 100 r.p.m. If a special propeller is not being used, a speed of approximately 1,400 r.p.m. should not be exceeded for more than a few minutes at a time with the airplane on the ground. If a thermocouple is used, speeds may be increased until the cylinder head temperature reaches 500°F. The remainder of the run-in may be put on in cruising flight, with a final run of about 30 min. at a speed

approximately 100 r.p.m. less than full throttle. Any flight run-in should be made over the airport in order that a quick landing may be made if any trouble develops.

If new pistons have been installed, the cylinders should again be removed and the pistons and cylinder walls inspected. If found to be in perfect order, reassemble and warm up for 20 min. before final test flight.

FRANKLIN ENGINES

Franklin engines, built by Aircooled Motor Corp. of Syracuse, N.Y., are made in four sizes: models 4AC-150, 4AC-171, 4AC-150A, and 4AC-176. The last is the latest and most powerful (see Figs. 6 to 11).

These are all four-cylinder, opposed, air-cooled engines. The general details are given in Table 6. Variations in horsepower depend on compression ratios and speed, and are particularly noticeable in the 4AC-176 engines where variations of 300 r.p.m. and from 6.3 to 7.1 compression ratios give from 65 to 80 hp. The cylinders are of high-grade aluminum alloy with a steel liner.

Table 6.—Franklin Air-cooled Engines

Model no.	4AC-150	4AC-150A	4AC-171	4AC-176
Horsepower	50	60	60	65 to 80
Rated r.p.m.	2,300	2,400	2,350	2,200 to 2,500
Cruising r.p.m.	2,100	2,200	2,150	
Bore, in.	$3\frac{5}{8}$	$3\frac{5}{8}$	$3\frac{7}{8}$	4
Stroke, in.	$3\frac{5}{8}$	$3\frac{5}{8}$	$3\frac{5}{8}$	$3\frac{1}{2}$
Compression	6.6 to 1	6.9 to 1	6.25 to 1	6.3 to 7 to 1
Displacement, cu. in.	150	150	171	176
Oil pressure, lb.	35–45	35–45	35–45	35–45
Oil temperature, max. deg. F.	225	220	225	240
Sump capacity, qt.	4–5	4–5	4–5	5–8
Valve clearance*	0.04	0.04	0.04	0.04
Firing order	1-4-2-3	1-4-2-3	1-4-2-3	1-4-2-3
Magneto	Eisemann	Eisemann	Eisemann	Eisemann
Spark advance:				
Magneto 1	30 deg.	30 deg.	30 deg.	28 deg. at 7 to 1 ratio
Magneto 2	H† = 28 deg.	H = 26 deg.	H = 28 deg.	30 deg. at 6.3 to 1 ratio
	L = 25 deg.	L = 24 deg.	L = 25 deg.	
Spark plugs	Champion J-10	Champion J-10	Champion J-10	Champion J-10
Carburetor	Marvel-Schebler MA-3-F	Marvel-Schebler MA-3-F	Marvel-Schebler MA-3-F	Marvel-Schebler MA-3-F

* This measurement is with no oil in valve lifters.
† H = high plug; L = low plug.

As the general construction of these engines is the same, many details of design are similar if not identical, and both care and maintenance can be handled in the same way. Valve clearance is a good example. All of these engines use the hydraulic zero-lash lifter. The clearance shown is 0.04 in.; this means with no oil in the lifter and the lifter fully depressed. Before the engine is started, the lifters should be filled with oil.

Rotation is counterclockwise, facing the propeller. Allowable wear of parts before replacement is shown in Tables 7, 8, and 9. Model AC-176 differs from the earlier models in a few details: Crankshaft bearings: front 3 in. (same); center, $1\frac{7}{16}$ in.; rear $1\frac{1}{2}$ in. The crankshaft extends $3\frac{21}{32}$ in. beyond the inner flange. The oil reservoir holds from 5 to 8 qt. of oil. An oil ring groove is cut below the piston pin but no ring is installed at the factory. The groove is for use in case it is impossible to control the oil

without it. A ring should not be added without consulting the service department of the builders.

Installation and detail drawings of the Franklin engines are shown in Figs. 6 to 11. Figure 6 shows the way in which the motors are mounted in the plane, with general dimensions, including the holes for the mounting bolts.

In Fig. 8 are details of the hydraulic valve lifter and the way in which oil is forced out for measuring valve clearance. Connecting rod construction is shown in Fig. 9. Figure 10 is a section showing both crankshaft and camshaft, and Fig. 11, a partial section through the cylinder and valve action.

Specifications for the mounting of 4AC-176 engines are shown in Fig. 6.

Models 4AC-150, 4AC-171. *Crankcase.*—The crankcase is a one-piece casting of high-strength aluminum alloy with a removable top cover. This allows for inspection of, and access to, connecting rods, connecting rod bearings, and other internal working parts. Maximum strength in the case is obtained by means of a center strut and two through bolts located in the front and rear of the case.

The crankcase has three main bearings, the front one being 3.00 in. overall, the center bearing 1¼ in. overall, and the rear bearing 1 7/32 in. overall. The main bearings are interchangeable and are steel backed. The thrust bearing is lined with babbitt, the center and rear with copper lead. The propeller thrust is taken on the long bearing next to the propeller. The thrust bearing is designed for either pusher or tractor installations.

Oil channels are drilled in the crankcase to provide flow of oil from the pump to the hydraulic valve tappets, main bearings, connecting rod bearings, camshaft bearings, overhead valve mechanism, and other working parts.

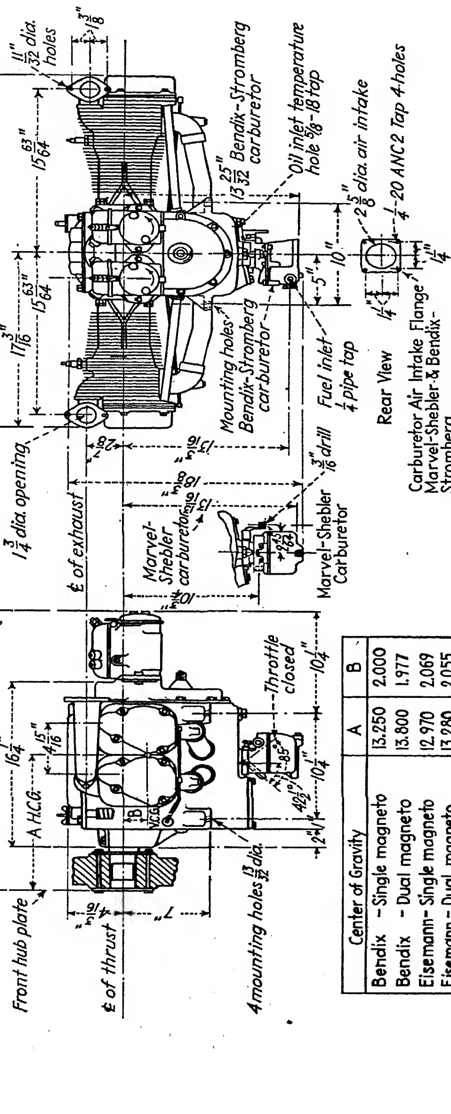
Cast integrally with the crankcase are four mounting lugs drilled for bolts that provide for horizontal mounting in compression. This ensures a light yet extremely rigid mounting, permitting the removal of the engine without dismantling it.

Crankshaft.—The one-piece, alloy steel, four-throw, three-bearing crankshaft is counterweighted and is balanced both statically and dynamically. It is drilled for lightness and to provide pressure lubrication of all bearings. *The propeller hub inner flange is forged as an integral part of the shaft.* It extends 3½ in. beyond the inner flange so as to provide full bearing support for the propeller. This eliminates many propeller hub assembly parts, and propeller trackage difficulties.

Camshaft and Timing Gears.—The camshaft is a one-piece steel forging. The eight hardened cams provide a firing order that ensures maximum smoothness. The camshaft timing gear is of Celeron which makes for longer life and quieter operation; the crankshaft timing gear is of steel.

Connecting Rods and Pistons.—Steel, drop-forged connecting rods are of conventional design with a bronze bushing pressed in the piston pin end. The big end bearing is fitted with a precision replaceable bearing shell of steel-backed copper lead and is drilled to throw oil spray on to the cylinder walls and the piston pin. The upper end of the connecting rod has three holes drilled to the boss and through the bronze bushing.

The pistons are cast of aluminum alloy. Piston pins are full floating. Two ring combinations have been used. One has Perfect Circle ⅛ in.; Type "200" rings in the top groove, a Simplex ⅛ in. molium ring in the second groove, and a Simplex 3/16 in. molium ring in the bottom groove. This combination has been used only on model 4AC-150 engines up to No.



Center of Gravity	A	B
Bendix - Single magneto	13.250	2.000
Bendix - Dual magneto	13.800	1.977
Eisemann - Single magneto	12.970	2.069
Eisemann - Dual magneto	13.280	2.055

FIG. 6.—Installation dimensions of Franklin engines.

1500. The other combination has a Perfect Circle ⅛ in., Type "200" ring in the top groove; a Perfect Circle ⅛ in., Type "70" ring in the second

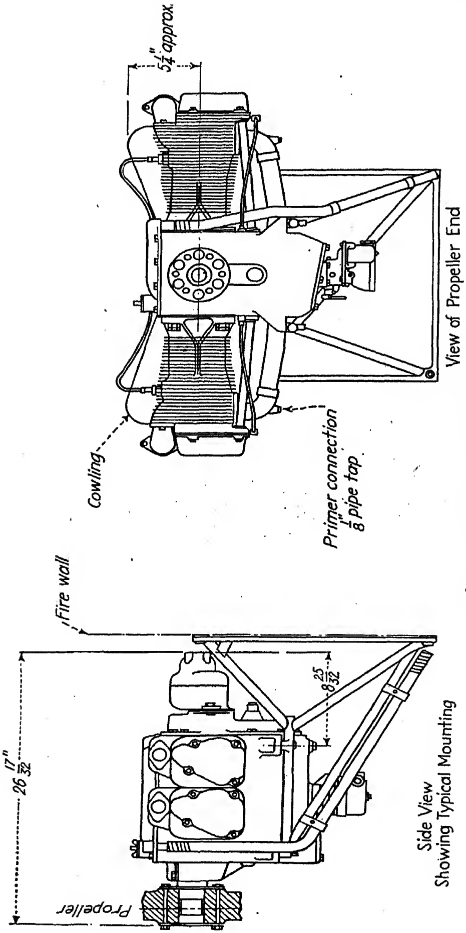


FIG. 7.—Details of mounting supports.

groove; and a Perfect Circle 3/16 in., Type "85" ring in the bottom groove. The pistons are fitted to 0.00725- to 0.00875-in. clearance.

Cylinders.—Cylinders and cylinder heads are cast together in one piece, of British "Y" alloy. Each cylinder has 33 fins, providing an abundant

heat-dissipating area. Into each cylinder is inserted a nickel-iron alloy liner, to a high shrink fit. This construction, with the use of metals of similar expansion characteristics, permits close tolerances, high compression ratios, and the use of low octane fuels.

Valve Mechanism Assembly.—Each cylinder has two overhead valves, each with a different axis. This provides sufficient area for the proper flow of air over the intake and exhaust ports. The head of the exhaust valve is of 2112 alloy steel and the stem is of S.A.E. steel. The intake valve is of S.A.E. 3140 steel. Valve seats and valve guides are of nickel-iron alloy, inserted into the cylinder head to a high shrink fit.

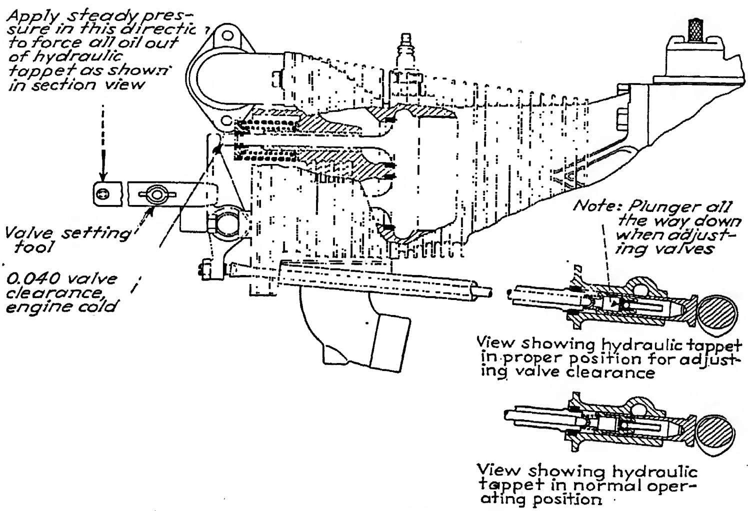


FIG. 8.—Details of hydraulic valve lifter.

Valve springs are made from Swedish wire and all are magnafluxed. Valve rockers are force-feed lubricated and the exhaust rockers are drilled to provide oil spray lubrication to the valve stems and valve springs.

Wilcox-Rich hydraulic valve tappets provide for automatic valve adjustment and eliminate valve adjustments between top overhauls. They are controlled by engine oil pressure and compensate for the expansion of cylinder and valve gear up to 0.200 in. backlash.

Lubrication System.—The engine is designed so that the oil reservoir is an integral part of the crankcase. Being a wet sump type engine, it requires no extra tanks or plumbing for the oil system. The normal capacity of the oil reservoir is 4 qt., although an extra quart may be used without overloading the engine.

The oil pump is of the unit-gear type, incorporating unusually wide gears. Because both pump body and gears are made of aluminum alloy, the clearance between them is not affected by temperature changes. This assures

normal oil pressure at all operating temperatures. A removable base plate makes it easy to remove the oil pump when desired.

Oil is pressure fed to the hydraulic valve tappets, main bearings, connecting rod bearings, and valve rocker mechanisms. The valve stems and springs are lubricated by spray from holes drilled through the exhaust rockers. The cylinder walls and piston pins are lubricated by oil spray from holes drilled in the big end bearing of the connecting rods. The timing and accessory drive gears are continuously bathed in oil.

The oil pump pressure relief valve is located in the pump casting and is set at the factory to give correct oil pressure of 35 to 45 lb. The oil strainer is located inside the oil reservoir at the inlet to the oil pump. The oil level gauge is combined with the oil filler and is located at the top left front side of the engine.

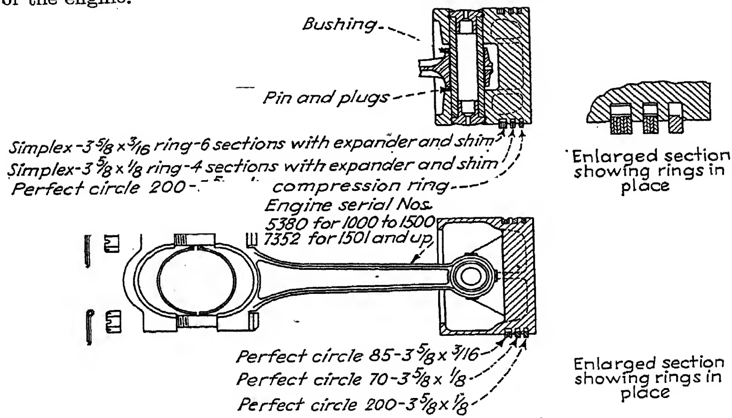


FIG. 9.—Connecting rod and piston construction.

Carburetion.—The carburetor is of the updraft type. The gasoline vapor mixture from the carburetor passes through the intake manifolds which are cast in the crankcase. As these manifolds are bathed in oil, vapor mixture is thus warmed and, at the same time, the oil temperature is decreased. Individual intake pipes connect this manifold to all four intake ports. Primer connections are provided to facilitate cold-weather starting.

Ignition.—The engine is equipped with single or dual magnetos having impulse couplings that assure easy starting under all conditions.

Installation. *Unpacking Franklin Engine.*—These engines are shipped in standard Franklin crates. Except for the carburetor, which is detached and packed separately in the crate, each engine is equipped with all accessories ready to install in the airplane. Each engine is fastened in the crate by means of bolts through the regular mounting lugs. After the top lid of the crate has been taken off, the engine is removed by simply loosening the four bolts that hold it to the bottom. The oil sump has been drained and the various oil holes plugged before shipment. Naturally, a certain amount of oil will remain in the oil leads in the hydraulic tappets, because it is impossible to remove all of the oil unless the engine is totally dismantled.

Mounting the Engine.—Installation diagram (Fig. 7) shows a typical engine mounting. It applies to models 4AC-150 and 4AC-171. The engine is bolted to the mounting at four points. A material similar to automotive brake lining should be used to insulate the engine from the mount at these four points. If, for any reason, it is necessary to remove the engine from the ship, care must be taken when replacing it. The same thickness of insulating material must be used at each mounting point, in order to ensure proper alignment of the mounting lugs and even tension on the crankcase.

Fuel System.—The gasoline inlet boss on the carburetor carries a ¼-in. pipe tap. To eliminate any possibility of foreign matter entering the carburetor, a commercial type gasoline strainer should be used between the gasoline tank and the carburetor. The gasoline line is usually specified by the plane maker. However, in certain special installations care should be taken that at least a ¼-in. diameter piping is used. It is recommended that a flexible type of pipe, other than copper tubing, be used, because copper tubing is liable to crystallize and fail. The shutoff cock should be installed as close to the carburetor as possible in order to eliminate any possibility of vapor-lock troubles during hot weather.

Oiling System.—A ⅝-in.–18 S.A.E. thread-tapped hole is provided at the bottom of the crankcase alongside the carburetor, for connecting the oil temperature gage bulb. A ⅛-in. pipe tap at the left rear of the crankcase (looking forward from the pilot's seat) is provided for the oil pressure gage connection.

Ignition System.—The Eisemann magneto is standard equipment. Bendix and Wico magnetos are optional. It is recommended that extreme care be used when installing the magneto grounding wire which runs from the magneto breaker cap through the switch to the motor mount. This is to prevent any premature starting of the engine, which might occur should the wiring be faulty. The magneto is shorted through this wire when the ignition switch is in the "off" position.

The Eisemann magneto is provided with an impulse starter to retard the spark automatically. This assures easy starting, as the propeller is pulled through slowly. The spark advance on Bendix and Wico magnetos is manually controlled by a Bowdin wire on the instrument board. A manual spark control is necessary for either of these magnetos for starting in order to eliminate the possibility of the engine's kicking back when it is pulled through.

Attaching the Propeller.—An unusual feature of the Franklin aircraft engine is the fact that the propeller hub is an integral part of the crankshaft. This design eliminates many hub assembly parts, permits of easy mounting and demounting of propeller, and assures proper propeller tracking. The propeller is mounted by simply backing it on to the crankshaft up to the rear propeller flange which is forged on to the shaft, affixing the front duralumin plate, passing the six bolts through the front plate, propeller, and rear flange, and tightening the bolts in place. The crankshaft extension is long enough to act as a full bearing surface for the propeller. If care is used to tighten the six bolts evenly, proper trackage will result. The tips of the propeller should track within ⅛ in.

To remove the propeller, simply take out the six propeller hub bolts and pull the propeller off. Another precaution to observe when installing the propeller is to locate it relative to a particular cylinder, so that a man starting the engine will be able to pull it through compression in a normal manner. Any propeller of approved design may be used on Franklin aircraft

engines. It should load the engine sufficiently so that the full-throttle r.p.m. does not exceed the C.A.A. rated speed.

Maintenance and Inspection of 4AC-150, 4AC-150A, and 4AC-171. *Ten-hour Inspection.*—Remove and clean the gasoline strainer. When replacing the glass bowl, be sure to get all the air out of the gas line by first fastening the bowl loosely, so that when the gas is turned on it will force all of the air out through the gascolator. As the gasoline begins to overflow, tighten the bowl so as to stop the gasoline leak.

Wipe off spark-plug insulation in order to eliminate dirt and soot on the outside of the plugs which might cause a short circuit. Inspect the ignition cable terminals at both the spark plug and magneto to see that they are tight.

The 25-hour Inspection.—Many owners prefer to drain the oil every 25 hr. The oil should be strained through a 20-mesh, or finer, screen, to make certain that no metallic particles are present. The presence of such particles serves as a warning that some part in the interior of the engine requires alteration or attention. An engine should see many hundreds of hours of service before any metallic particles appear.

Oil all spark and throttle controls. Make sure that they operate through the full range without binding. Check and clean the spark plugs. Gaps should be set to approximately 0.025 for the J-10 Champion plugs, or 0.015 for the Scintilla 14AB.

Extreme care should be exercised to prevent stripping the thread in the aluminum alloy cylinder head when the spark plug is tightened in position. In other words, do not tighten the spark plugs excessively.

Check all high-tension cables and terminals. If either terminal is corroded, the cable assembly should be replaced. It is also very important that the insulation on the cable be in good condition, otherwise a high-tension spark might jump from the cable to the engine, thus causing it to misfire. Check the propeller track and the breaker points on the magneto.

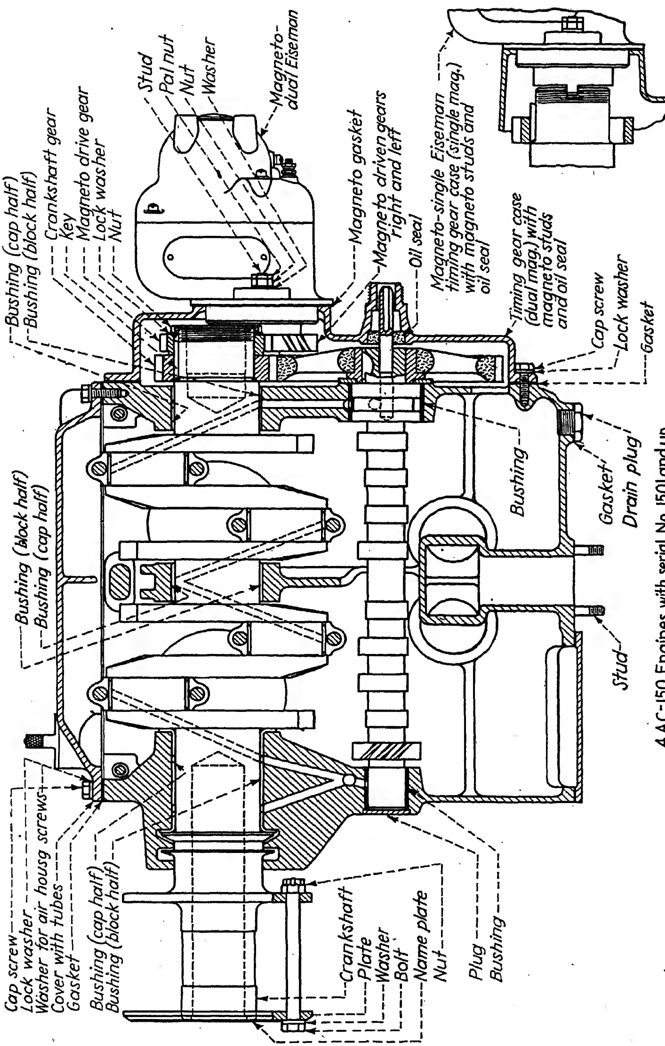
The 100-hour Inspection.—Remove the valve covers and check the valve guides for wear. This is done by pressing on the side of the spring with a screw driver to see how much they move back and forth. Excess clearance on the guides means that the valves cannot seat properly, because the action of the rocker arm will push the valve sidewise in the guide. Excess clearance around the exhaust-valve stem would permit the exhaust gas to force the lubrication from the stem and result in excessive wear.

Excessive clearance on the intake stem permits the engine to receive additional air at this point. This will cause the air to "lean" the mixture and result in increased cylinder head temperature.

Remove and clean the carburetor. Dirt in it may prevent the engine from turning up properly. The carburetor should be taken off and cleaned thoroughly by an experienced workman. However, the average mechanic, if he is careful, can do a satisfactory job. It is extremely important to remember that in cleaning the carburetor jets, they should be blown out with air. If cleaned with wire the jets may be made oversize, with the result that the carburetor will not meter properly.

Clean out all gas lines, strainer, etc. Remove the gas tank shutoff in the tank and clean the small strainer which is attached. The gas tank should be washed out with clean gasoline in order to remove any trace of sediment.

Top Overhaul.—Although in many cases top overhaul may not be required between major overhaul periods, good practice indicates that a top overhaul



4 AC-150 Engines with serial No. 1501 and up

Fig. 10.—Section through crankshaft and camshaft.

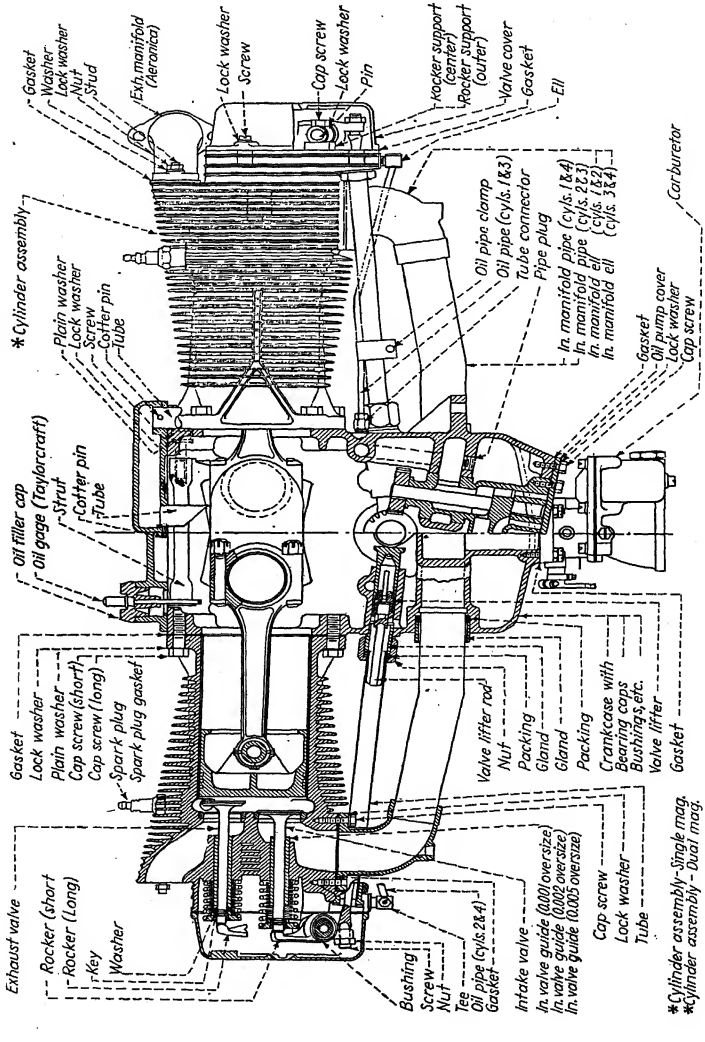


FIG. 11.—Partial cross section with parts named.

every 250 hr. be given in order to ensure continued maximum performance and operating economy.

The following inspection and adjustment should be made before revving up the engine to full throttle on the ground in order to determine the possible need for a top overhaul:

See that spark is set at the correct position. Settings are given on the name plate attached to the engine and on page 346.

Check over the various items covered in the 10-, 25-, and 100-hr. checks.

See if the carbureter throttle lever will open the throttle valve all of the way when against the forward stop.

While the engine is cool and ignition switch is off, test the compression of each cylinder. A good plan is to have one person turn the propeller slightly, while another listens for blowing valves in the exhaust ports and through the carburetor inlet. This test should be made with the throttle wide open.

After checking thus and making any necessary adjustments, start the engine and warm it up until the temperature of the oil is approximately 100°F.; then open the throttle (spark fully advanced) and note the maximum r.p.m. If the engine does not turn up to required minimum speed with proper propeller attached, it is possible that a top overhaul is necessary.

The top overhaul of the Franklin aircraft engine is easily accomplished without removing the engine from the ship. First, place the ship in a clean, protected spot free from dust and dirt. Take off the cowling over the engine and remove the air housings. The engine should then be dusted off with compressed air, if possible, then washed completely with gasoline and a brush.

Take out the spark plugs and remove the cylinders from the engine. The cylinder will probably require a gentle rap with a wooden hammer in order to break the gasket loose from the crankcase. The cylinder should then be slightly raised from the crankcase, taking care to see that the piston, as it emerges from the cylinder, does not drop down and hit the cylinder base studs. A safe way to prevent this is to slip a piece of small rubber hose over the lowest base bearing studs on each cylinder. Immediately after removing the cylinders, it is advisable to remove the propeller, otherwise, if it is turned while the cylinders are off, the pistons may be damaged. Scrape all carbon from the interior of the cylinder head while the valves are still in place. This will protect the valve seats.

To remove a valve (Fig. 8) place a block of wood 7⅛ in. long inside the cylinder, with the cylinder resting on the bench, and remove the valve cap. This will permit access to the valve mechanism.

To remove the springs, press down on the outside of the spring until the split cone is removable. A steel bar approximately ¼ × 1¾ in. wide and 14 in. long with a ¾-in. hole through the center is useful for compressing the valve springs. Remove the retainers, springs, and valves, keeping note of their correct location so that they may be put back in the same position when the engine is reassembled.

Clean all parts with gasoline and inspect the valves for cracks, burning, and stem wear. Also examine the valve seats carefully for cracks and burning.

Do not reface the valve seats unless absolutely necessary, as a refacing operation sometimes removes more material from the seat than is required. It may even be necessary to install new seats; if so, the cylinder should be returned to the factory, as these valve seats are shrunk into it. Arrangements may also be made before reseating the valve, the valve guide should

be inspected. If more than 0.004 in. wear is found, the valve guide should be replaced because it is impossible properly to seat the valve if the valve guide has excessive clearance. For the method of changing guides, see page 342.

If it is absolutely necessary to reface the valve seats, a set of 30-deg. reseating cutters should be used. Two cutters will be required, one $1\frac{11}{16}$ in. in diameter for the intake seat, and one $1\frac{1}{2}$ in. in diameter for the exhaust seat. The pilot bar should be of $\frac{3}{8}$-in. diameter for both intake and exhaust guides. The cutters should be used sparingly or they will remove an excessive amount of metal. Care must be taken to see that they cut evenly, otherwise the seat will be wavy and will require an excessive amount of hand-lapping to remove the wave.

The reseating operation of the valve seats is one that must be done with a great deal of care. An extra wide valve seat means that the aluminum which is rolled over to help hold the seat in position is cut away. It means that the seat has nothing but a shrink fit to hold it in position. If the aluminum is cut away, it will be necessary to install new valve seats.

All carbon should be carefully cleaned from the valves, care being taken not to scratch the seats. It is also important to use abrasive cloth not coarser than No. 150 on the valve stems. Coarse cloth tends to remove the gloss from the stems together with the surface hardening produced by many hours of operation on the engine.

If the valves are burned, pitted, or grained, they should be refaced to a 30-deg. angle.

After the valves and seats have been reseated, they should be lapped in by using a very fine grinding compound so that there will be no chance for leaks. A final check for leaks should be made by pouring gasoline in the ports, or with air pressure directed to the combustion chamber.

Valve Springs.—Both inner and outer valve springs should be carefully examined for cracks after they have been thoroughly cleaned with gasoline. After they have been put back in the cylinder, they should be checked for loading. The valve springs, when assembled to the cylinders, should support 63 to 68 lb. when the valve is on its seat. If the spring weight does not support at least 63 lb., the spring should be removed and washers placed under both the inner and the outer spring in sufficient numbers to bring tension up to the required limits. A weak spring tends to cause uneven firing under part throttle operation, while more than 68 lb. tends to overload the hydraulic unit. If more than two $\frac{1}{16}$-in. washers are needed to bring the spring to the necessary tension, it shows that the springs have weakened to a point where they must be replaced.

Rusty springs should all be replaced, as they are apt to crack and break.

Cylinders.—Cylinders should be checked for taper and out-of-roundness with an inside micrometer. A tapered cylinder, or one which is more than 0.002 or 0.003 in. out of round, should be returned to the factory and exchanged for cylinders of normal size, that is, 3.626 to 3.625 for 4AC-150, or 3.8745 to 3.8755 for 4AC-171. This method of handling excess clearance is less costly to the operator than to regrind the cylinders and use oversize pistons.

Before assembly, be sure that all parts are absolutely clean and in first-class condition. As the parts are being put together, oil all bearing and other contact surfaces in order to avoid the possibility of scuffing when the engine is first started. If the valve leak test shows the valves to be tight and if the cylinder has normal clearance, the valve mechanism can be reassembled to

the unit. Make sure that the narrow end of the rocker pin is installed so that the chamfer at one end is toward the center of the cylinder; otherwise there will be interference with the valve spring. Make sure that the oil hole in the rocker pin bearing is directed toward the cylinder. Take particular care that the barrel end of the rocker arm lines up with the center of the valve stem. This alignment can easily be obtained by a slight tightening of the nuts on the rocker support studs. Then tap the rocker arm around until it lines up properly; then tighten the nuts and cotter pin.

Do not install the valve rocker caps on the cylinder until the cylinders have been installed on the crankcase, because it will be impossible to see whether the lifter rods are lining up properly at the ball end of the valve adjusting screws.

Assembly of Cylinders to Crankcase.—Before the cylinders are assembled to the crankcase, the interior of the crankcase should be inspected and cleaned. Before attaching the cylinders, make sure that all parts are absolutely clean and in good condition. Make sure that new gaskets are used beneath the cylinder. The possible saving in using an old cylinder gasket may be more than offset by the added cost of an oil leak.

Cover the piston rings and the interior of the surface with a good coating of lubricating oil. Use a band type of ring clamp over the piston ring before attempting to pilot the cylinder on to the piston, then push very carefully, otherwise the rings may be cocked and broken.

Draw up evenly on each of the six bolts that fasten the cylinder to the crankcase.

The next important step is to adjust the valve clearance. With cylinder 1 at the firing position and using the proper tool, *pull back on the rocker arm until all the oil is forced out of the hydraulic tappet.* This condition will be apparent when continued pressure no longer alters the gap between the valve stem and the rocker arm. At the time the final measurement is made for adjustment, the pressure on the rocker arm should be released as much as possible, without allowing the push rod end to move. In other words, the pressure at the time of measurement should not be sufficient materially to spring the rocker arm. With the rocker arm in this position, it is a simple matter to adjust the screw on the push rod end to a point where a 0.040 gap is measurable between the top of the valve and the rocker arm. If the engine has been totally dismantled and the hydraulic tappet cleaned and washed out, it will be unnecessary to squeeze the oil out of the tappet inasmuch as there will be no oil beneath the piston of the hydraulic tappet unit.

Clean all the spark plugs and check the gaps to see that they are 0.025 in. for the Champion J-10 plugs, or 0.015 in. for the Scintilla 14AB. Care should be taken that there are no burrs on the threads of the spark plugs. This can be noticed if the plugs go in hard. In other words, if a plug cannot readily be screwed into position with the fingers, it is evident that there is a burr on the plug. In this event the plug should be carefully removed and the burr filed off. Extreme care should be taken to see that the plug is started straight, as experience has shown that cylinders have been ruined because the plug was started in cocked and forced in with a wrench.

In installing the exhaust manifolds and air housings on the engine, be sure that the nuts on the studs, which hold the exhaust manifold in position, are not tightened too tightly. Otherwise the aluminum alloy exhaust manifolds may crack. Bring the nuts up to a snug position, without forcing.

It is recommended that the engine be run in on the following schedule:

R.p.m.	Min.	R.p.m.	Min.
1,000	30	1,600	20
1,100	30	1,700	20
1,200	30	1,800	20
1,300	30	1,900	20
1,400	30	2,000	20
1,500	30	2,100	20

If new piston rings or pistons have been put in the engine, modify the run-in, as follows:

R.p.m.	Min.	R.p.m.	Min.
1,000	30	1,700	20
1,200	30	1,900	20
1,500	30	2,100	20

Piston Rings.—After a cylinder is removed, it is usually best to install new piston rings, because the average ring begins to lose its effectiveness at about the same time as the valves. The ring grooves should be thoroughly cleaned, and new rings installed. The top of the piston should be cleaned with crocus cloth dipped in kerosene. It is not necessary to remove the piston from the rod in order to install new piston rings.

Should it be desirable to remove a 4AC-150 piston pin it will be necessary to heat it with a blow torch, to approximately 250 deg., before the pin can be driven out. If the piston is badly scratched, it can be refinished somewhat with crocus cloth. However, if the scratches are very deep and numerous, it is best to replace it with a new piston. On the 4AC-171 engine, it is not necessary to heat the piston as the pin is assembled with a push fit.

To install the piston pin it will be necessary to heat the piston to 250 deg., otherwise the pin will not enter it. This applies to model 4AC-150 only.

If a new 4AC-150 piston is necessary, it should be purchased with the pin fitted, in order that the proper clearance shall exist between the piston and the piston pin.

In the Perfect Circle–Simplex Molium ring combination, a Perfect Circle ⅛ in., Type "200" ring, is fitted in the top groove. This Perfect Circle ring is mounted so that the cutout on the inner edge is toward the piston head, or top. Simplex ⅛ in. and 3/16 Molium rings are used in the second and third grooves respectively. Simplex rings have been used on 4AC-150 engines up to No. 1500 only. Special instructions for the installation of Simplex Molium rings follow:

Be sure the ring groove is clean.

Slip a shim into the groove, noting the position of the gap.

Slip an expander over the shim so that the gap and expander are 180 deg. to the gap and shim.

Slip rings into groove, one at a time, so that all locating tangs are at the same side of the gap. This will make it unnecessary to invert some of the rings.

Locate the rings so that the tangs on the inside of the rings are between the humps on the expander in such manner that when installation is complete, the gaps in every other ring will be in line.

In the all Perfect Circle ring combination, a $\frac{1}{8}$-in., Type "200" ring is fitted in the top groove so that the cutout on the inner edge is toward the piston head, or top. In the second groove a $\frac{1}{8}$-in., Type "70" ring is installed with the cutout section toward the skirt; in the third groove, the $\frac{3}{16}$-in., Type "85" oil ring is installed. Be sure that the gaps do *not* line up.

Complete Overhaul.—A complete overhaul should not be required before 500 hr. However, unusual circumstances, such as excessive oil consumption, the appearance of metal particles in the oil, or erratic operation in flight, may make a complete overhaul advisable before that time. In examining any part for wear, consult Tables 7, 8, and 9 to see how much wear is permissible before the part should be replaced with a new one.

Complete Disassembly.—To disassemble an engine completely, it must be first removed from the plane. Remove the propeller by taking out the six bolts that attach it to the hub and crankshaft. Remove the exhaust pipes, throttle controls, gasoline line, etc. Then the engine may be easily lifted out of the plane by two persons.

The engine can be disassembled on a bench or on an assembly stand. Because it is obviously impossible to do a first-class job unless all parts are well cleaned, the exterior of the engine should be thoroughly cleaned with gasoline before any work is undertaken. It is usually a good plan to have several clean boxes or cans available in which to place the parts as they are removed from the engine. Each separate part should be thoroughly washed with gasoline.

Caution. To prevent damage to parts, always use a fiber drift or mallet whenever it is necessary to separate or drive parts together.

Remove cylinders and pistons as in top overhaul.

Remove the magneto, carbureter, crankcase cover, and timing gear case cover.

To remove the crankshaft it will first be necessary to remove the long tie bolts, and the center crankcase strut, permitting the removal of the bearing caps. If difficulty is experienced in removing them, use a wooden pry bar and tap the cap slightly with a wooden mallet before prying it off.

To remove the camshaft, unscrew the two machine screws that hold the camshaft thrust washer in position. The camshaft can then be pulled out through the end of the case. It is not often necessary to remove the camshaft. However, removal will permit an inspection of the hydraulic tappet bodies. On those engines equipped with a fuel pump, remove the pump and plunger before pulling the camshaft.

Remove the oil pump, as outlined in Top Overhaul.

Inspection and Replacement of Parts.—After disassembly, all parts should be cleaned and laid out in groups for inspection. As they are examined, make a list of all defects and all parts that are to be replaced. The correct clearances for the parts are shown in Tables 7, 8, and 9.

Hydraulic Tappet Assembly.—The valve tappet bodies should slide freely in the guide bosses in the crankcase; they seldom have to be replaced for wear. However, they will sometimes require replacement due to "parking." Where they have not been rotating in the guide bosses, the cam marks a straight line across the faces.

Although the hydraulic valve tappet unit will usually last indefinitely, if it seems weak, or incapable of pressure, it is well to replace it.

Valve Tappet Actuating Unit.—To assemble the valve tappet actuating unit properly, use a short piece of lacing wire, preferably copper, and insert it in the oil tube at the bottom of the tappet cylinder. This will raise the

ball check from its seat and allow the unit to compress easily. After the unit has been pushed together, the spring should be snapped into the cylinder by pushing and twisting, in a clockwise direction, on the spring. This clockwise twisting should be used on both assembly and disassembly.

Push Rods.—The ball end must fit tightly to the inside of the push rod, otherwise it will work up and down and cause erratic valve operation. If the ball end and cup end are not smooth and free from wear, they should be replaced.

Camshaft Assembly.—The camshaft should be examined for wear on the bearing and cam surfaces. If the edges of the cams are worn or chipped, the camshaft should be replaced or the valve tappet foot will become worn on the ragged edge of the cam. Usually the camshaft bearings will last the life of the engine. They should, however, be checked in order to see that wear is not excessive.

If the camshaft bearings are worn, the crankcase should be returned to the factory so that new ones may be properly installed. Their installation is not a job that can usually be done in the field, owing to the difficulty experienced in keeping the axis of the camshaft bearings parallel with the axis of the main bearings. It is also important to keep the center distances correct.

Camshaft Gears.—It will seldom be necessary to replace the crankshaft gear. It may be necessary to replace the Celeron camshaft gear, if the edges of the teeth look flat, or if there is excessive backlash between the crankshaft and camshaft gear teeth.

Cylinder Assembly.—Examine all cylinder parts as in Top Overhaul.

It is not often necessary to replace valve guides until after 450 to 550 hr. of service. Should it be necessary to replace them, all cylinders requiring new valve guides should be returned to the factory. This is recommended because the guides are shrunk into the aluminum cylinder under heat, at definite limits. When this work is done at the factory, the guide and the cylinder hole are carefully checked and oversize valve guides selected to give the proper fit.

Some operators may desire to make the guide installation themselves. The best method for removing the valve guides is to break off that part of the guide that extends into the rocker box, with a hammer. The guide will break just inside the cylinder head. The guide must then be spot-faced with a $\frac{9}{16}$-in.-diameter spot facer, using a $\frac{3}{8}$-in. pilot. Then, set the cylinder under an arbor press and use a $\frac{9}{16}$-in. arbor to push the guide down into the cylinder. This should be done while the cylinder is cold.

It is imperative that this method be used to push out the guide because, if it is pushed out the other way, the lower part of it will tend to make the guide hole in the cylinder oversize.

When installing new guides, use a special replacement part which is 0.001 in. oversize. If the guide hole becomes damaged, a 0.005-in. oversize guide can be obtained, which may be used after reaming the guide hole oversize. To install the new guides, heat the cylinder head to 450 to 500°F., covering the new valve guides with white lead; then drop them in place. After the cylinder has cooled, the guides will be shrunk in place and the cylinder is ready for use.

If the engine has been in service for 450 to 550 hr., the usual practice is to install oversize pistons, reboring the cylinder to fit them. It is recommended, however, that the cylinder assemblies be returned to the factory and exchanged for cylinders with new cylinder liners, new valve seats, new valve guides, and new valves. Because the pistons on the engine will last indefi-

nitely, it is usually unnecessary to buy new ones, provided, of course, the ring grooves have not become excessively worn.

Under this plan of cylinder exchange, the operator receives new cylinder assemblies capable of giving the same service as new ones. In the long run this is more economical than to attempt to regrind the cylinders and install oversize pistons.

Rocker Arms.—Rocker arms usually last indefinitely, provided they have all been adequately lubricated. However, if the rocker arm bushing is badly worn, it should be replaced, otherwise the oil will not be directed up into the exhaust valve stem and will leak out the side of the rocker. Also, if the barrel end of the rocker arm is worn, the rocker arm assembly should be replaced. However, in case only the rocker arm bushing needs to be replaced, this can best be done at the factory where the bushings are precision bored to the correct diameter.

Pistons and Rings.—The pistons on the 4AC-150 should be carefully examined and cleaned. The piston pin should be a tight fit at a room temperature of 70°F. When the engine was new, the pin was shrunk fit into the piston. However, after several hundred hours of operation the pin is usually a tight push fit in the piston at room temperature. If the pin is looser than 0.0005 in. in the piston, it should be replaced with a 0.001-in. oversize pin.

If the pistons are badly scratched, or the ring grooves worn, a new piston should be used. If the ring grooves are in good condition on the piston or are only slightly scratched, rubbing with crocus cloth dipped in kerosene, or a fine oilstone, will correct the defect.

On model 4AC-171, the original fit at the factory between the piston and pin is a push fit at room temperature. After several hundred hours of operation the pin is usually a loose fit; if looser than 0.001 in., it should be replaced with a 0.001-in. oversize pin, or a pin of a size to fit the worn pin hole.

It is good practice to use new piston rings when completely overhauling the engine. The new rings should fit freely into the piston grooves of the piston, otherwise there may be a tendency for the rings to stick when the engine is again placed in operation.

Piston Pins.—The piston pin should be carefully examined to see that the aluminum plugs fit tightly in the pin proper. If they do not, the entire pin assembly should be replaced.

Crankcase.—The crankcase is cast in one piece, in which maximum strength and rigidity are assured by center strut and tie-bolt bracing. Each case is machined with specific bearing caps. If a bearing cap requires replacement, it is recommended that the crankcase be returned to the factory to have a new cap installed. Misalignment between the three bearing bores will deflect the crankshaft and may be the cause of crankshaft and crankcase failure.

Timing Gear Case.—The timing gear case should be thoroughly examined, primarily with the idea of seeing that there are no cracks in it. Also be sure the tachometer drive leather oil seal is functioning properly. If the leather appears torn or incapable of sealing the tachometer drive shaft properly, it should be replaced very carefully as the seal is quite fragile and will bend easily. This is best done on an arbor press. If none is available, the old seal can be driven out and the new seal tapped in position with a wooden block. Assemble the seal so that the spring is toward the camshaft gear.

Crankcase Cover.—Examine the crankcase cover for cracks and see that the crankcase breather tube is held in place with a cotter key. If the key is missing or shows evidence of being worn, a new key should be installed.

External Oil Lines.—Clean out all fittings and oil lines. Make certain they are clear, otherwise the valve mechanism will not receive the proper amount of oil.

Oil Pump Assembly.—The oil pump should be carefully examined to see that the gears are not worn or the pump scored. A new pump should be installed if there is any indication that it is not in first-class condition.

Intake Manifold Pipes.—The intake manifold pipes should be examined at the point where they fit into the cast aluminum elbow, to be sure that they fit tightly; otherwise they will permit air leaks and cause irregular operation. If the pipe does fit loosely, shellac the joint, press the two pieces together, then tape the joint with friction tape and shellac again to hold the tape in position.

Connecting Rod Assembly.—All connecting rods should be carefully examined for cracks, chips, etc. The cap bolts and nuts should be thoroughly inspected to see that the threads are in good condition. The small bushing in the upper end of the rod should be examined to see that it is not turned out of position. This condition can be corrected by lining up the oil holes in the connecting rod with the holes in the bushing. It should also be examined for wear. If it is larger than 0.861 in. the rod should be returned to the factory where new bushings, precision-bored to the right dimension, will be installed.

After 450 to 550 hr. of operation, it is recommended that new connecting rod bushings be installed. Before ordering bushings, measure the diameter of the crankpins to see that they are not worn excessively. The connecting rod had an original clearance, when the engine was built, of 0.0015 to 0.0035 in. If the clearance has increased beyond 0.006, the crankpins should be reground 0.010 undersize or 1.9275 to 1.9270.

Crankshaft.—If the crankpin journals have worn 0.001 or 0.0015 in. out of round and are more than 0.001 tapered, the crankshaft should be reground to one of the standard undersizes. This regrinding job should be done only where proper facilities are available for that operation and for rebalancing the crankshaft.

The main journals should be measured for wear. If such inspection shows the diameter to be less than 2.248, or tapered in excess of 0.0015, or out of round more than 0.001, the shaft should be reground 0.010 undersize or 2.2395 to 2.2400.

The main bearing bushings should be examined carefully for wear or cracks. Also examine the thrust faces on the front main bushing.

Reassembly after Complete Overhaul.—It is important that the assembly of the engine be undertaken in a clean, light place, free from drafts that would tend to blow dirt on or into the engine. The crankcase should first be carefully washed with clean gasoline, then blocked securely in an upright position.

The first parts to go into the engine are the hydraulic valve tappet assemblies. These, when pushed into their respective bores, should have no tendency to bind or stick.

Next, wipe the camshaft bearings carefully with a clean cloth, oil the camshaft, and insert in the case. The camshaft will not drop fully into position until the thrust plate screws are tightened. These are tightened by alternately screwing in one and then the other, continuing until the thrust plate is tight. Be sure that the conical-shaped washers are in place to secure these screws. Rotate the camshaft to check its freedom of movement. *Then turn the shaft until the portion of the gear marked with an "O" is in line with main bearing bores.* Carefully wipe out main bearing bores, and insert

and oil the bearing shells. It is important that there be no dirt between the bearing shells and the bearing bore.

Caution. Be sure that the oil holes in the shells line up with those in the bearing blocks.

Oil the main journals and drop the crankshaft into the engine so that the "O" on the crankshaft timing gear meets with the same mark on the cam gear.

Table 7.—Fits and Clearances of Franklin Model 4AC-150, 4AC-150A

	Min.	Desired	Max.	Max. permissible after wear
Crankshaft bearings:				
Center and gear end	0.0015	0.002	0.0035	0.006
Propeller end	0.001	0.002	0.003	0.006
Crankshaft thrust bearing, end clearance	0.004	0.006	0.008	0.012
Connecting rod and crank pin	0.0015	0.0025	0.0035	0.006
Piston pin and rod	0.0002	0.0003	0.0006	0.002
Piston and piston pin	0.0001 tight	0.0005 tight	0.0006 tight	0.0015 loose
Cylinder liner and piston	0.00725	0.0075	0.00875	0.0125
Camshaft small bearing	0.001	0.002	0.0025	0.004
Camshaft large bearing	0.001	0.002	0.003	0.004
Camshaft end movement	0.002	0.003	0.006	0.010
Valve rockers and pins	0.002	0.003	0.004	0.006
Valve lifters and crankcase	0.001	0.001	0.002	0.004
Valve stems and guides	0.002	0.003	0.0038	0.006
Oil pump drive shaft and pump body	0.001	0.0015	0.0025	0.004
Oil pump driven gear and shaft	0.001	0.0015	0.002	0.004
Oil pump gears, pump body and cover	0.0035	0.004	0.0075	0.009
Backlash, camshaft and crankshaft gears	0.002	0.003	0.004	0.006
Piston ring and groove:				
Top (Perfect Circle)	0.004	0.005	0.006	0.008
Middle (Simplex Molium)	0.0074	0.0087	0.010	0.012
Bottom (Simplex Molium)	0.0091	0.010	0.00125	0.0145
Middle (Perfect Circle)	0.006	0.008	0.010	0.014
Bottom (Perfect Circle)	0.003	0.004	0.005	0.007
Side clearance, connecting rod and crankshaft	0.0020	0.00275	0.0035	0.0055

Carefully examine the bearing caps to determine whether they have been burred or damaged in any way while out of the engine. If so, it is imperative that they be cleaned up with a fine stone or bearing scraper. The oil sealing grooves on the front and rear caps should be cleaned out. If the caps have been found to be in good condition, the bearing shells may be inserted and the caps dropped in place. All the bearing caps are stamped with a number that identifies that set of caps and eliminates the possibility of the center cap's being reversed. All numbers are stamped so that they are legible from one side of the engine.

Make sure that steel washers are in place on the main bearing studs or screws before tightening. Bearing caps should be pulled down carefully and evenly. Insert the crankcase tie bolts, which should be pulled down until they are just snug. *Do not neglect to put in the rear motor strut fitting at this time.* It is advisable to use Permatex, or some other similar sealing compound, on the washers at the ends of the crankcase tie bolts.

Install the crankcase center strut. It is usually necessary to tap this in place with a block of wood. It is also good practice to use a sealing com-

pound (Permatex or its equivalent) on the steel washers under the screws that secure the center strut in place.

Seal the front main bearing with a short length of soft wicking at the lower outside edge of the cap, from the vertical sealing slot forward.

Caution. Do not allow packing material to get between the bearing cap and the block as this will tend to hold up the cap, relieve the crush on the bearing shell, and cause the shell to turn.

Table 8.—Fits and Clearances of Franklin Model 4AC-171

	Min.	Desired	Max.	Max. permissible after wear
Crankshaft bearings:				
Center and gear end	0015	0.002	0.0035	0.006
Propeller end	001	0.002	0.003	0.006
Crankshaft thrust bearing end clearance	004	0.006	0.008	0.012
Connecting rod and crank pin	0015	0.0025	0.0035	0.006
Piston pin and rod	0002	0.0003	0.0006	0.002
Piston and piston pin	0000	0.0002	0.0003	0.002
Cylinder liner and piston	006	0.0065	0.007	0.011
Camshaft small bearing	001	0.002	0.0025	0.004
Camshaft large bearing	001	0.002	0.003	0.004
Camshaft end movement	002	0.003	0.006	0.010
Valve rockers and pins	002	0.003	0.004	0.006
Valve lifters and crankcase	001	0.001	0.002	0.004
Valve stems and guides	002	0.003	0.0038	0.006
Oil pump drive shaft and pump body	001	0.0015	0.0025	0.004
Oil pump driven gear and shaft	001	0.0015	0.002	0.004
Oil pump gears, pump body and cover	0035	0.004	0.0075	0.009
Backlash, camshaft and crankshaft gears	002	0.003	0.004	0.006
Piston ring and groove:				
Top (Perfect Circle)	004	0.005	0.006	0.008
Middle (Perfect Circle)	003	0.004	0.005	0.007
Bottom (Perfect Circle)	002	0.00275	0.0035	0.0055
Side clearance, connecting rod and crankshaft	006	0.008	0.010	0.014

The crankshaft should now be turned over by hand to detect any binding or friction. If the shaft is quite free, insert the cotter pins in the main bearing studs.

Next install the timing gear case, using a new gasket. It is important that great care be used in slipping the oil seal over the tachometer drive spigot, because rough handling may damage the oil seat. Make sure that all dowel pins are in place before tightening the timing gear case to the block, as these dowels control the alignment of the magneto with the crankshaft. Next pack the oil seal slots in the front and rear main bearings. Packing material should be tamped in place with a small drift. Then push the magneto drive ring into the rear of the crankshaft and install the magneto. Engines equipped with Eisemann magnetos do not use this ring. They have an impulse starter that makes a direct connection.

Caution. Be sure that engine is set on center 1. This can be determined by pressing in on the two valve tappets on cylinder 1 and rotating the crankshaft several degrees in each direction to make sure that they do not move. If either valve tappet moves, the crankshaft must be turned over one full revolution to be in proper time. This position is indicated by the mark on the propeller hub flange on the crankshaft.

If the engine is equipped with single ignition, the position marked with an "S," when brought in line with the mark on the front main bearing cap, indicates 30 deg. before top center. This is the correct position for full

advance. The other two marks are used for dual ignition: "L" (left-hand magneto) marking the firing position of the low plug; "H" (right-hand magneto) marking the firing position of the high plug. These positions are, respectively, 25 and 28 deg. B.T.C.

Table 9.—Fits and Clearances of Franklin Model 4AC-176

	Min.	Desired	Max.
Crankshaft bearings:			
Center and gear end	0.0015	0.002	0.0035
Propeller end	0.0015	0.002	0.0035
Crankshaft thrust bearings and clearance	0.004	0.008	0.012
Connecting rod and crank pin	0.001	0.0015	0.0025
Piston pin and rod	0.0002	0.0003	0.0006
Piston and piston pin	0.0000	0.0001 tight	0.0002 tight
Cylinder and piston	0.0025	0.0030	0.0035
Camshaft small bearing	0.001	0.002	0.0025
Camshaft end movement	0.002	0.004	0.006
Valve rockers and pins	0.002	0.003	0.0035
Valve lifters and crankcase	0.001	0.001	0.002
Valve stems and guides	0.0025	0.0034	0.0043
Oil pump drive shaft and pump body	0.001	0.0015	0.0025
Oil pump driven gear and shaft	0.001	0.0015	0.002
Oil pump gears, pump body and cover	0.0035	0.004	0.0075
Backlash, camshaft and crankshaft gears	0.000	0.001	0.002
Piston ring and groove:			
Top (Perfect Circle)	0.0055	0.0062	0.007
Second (Perfect Circle)	0.0035	0.0042	0.005
Third (Perfect Circle)	0.002	0.00275	0.0035
Piston ring, butt clearance (for 4.000 diam. cylinder)	0.025	0.029	0.035
Side clearance, connecting rod and crankshaft	0.006	0.009	0.012
Push rod and crankcase (fuel pump)	0.002	0.002	0.006

Position 1 of the Bendix magneto is indicated by a white mark on the large magneto gear, which is visible through the small window at the top of the magneto.

This in itself gives only the approximate position. With the magneto held in this position, it can be pushed into place. Insert a piece of cellophane between the breaker points, advance the spark all the way, and rock the magneto until the cellophane just becomes perceptibly free between these points. If the cellophane does not become free in the full rocking range, the magneto must be pulled off again and the drive gear shifted one tooth. After the timing is set, tighten the magneto, turn the crankshaft opposite to the direction of rotation, then pull slowly in the direction of rotation, while maintaining tension on the cellophane between the points. When the cellophane becomes free, the crankshaft should be at the marked firing position.

To Check Eisemann Magneto for Correct Timing.—Turn the crankshaft until piston 1 is on compression stroke and the mark "S" on the flange is opposite the arrow on the bearing cap. For dual magnetos, in order to set the magneto that fires the low plugs, place the mark "L" opposite the arrow. To set the magneto that fires the high plugs, place the mark on "H" opposite the arrow.

Remove the distributor cap and make sure the distributor rotor points to position 1 on the distributor cap (the notch on the rotor should be at bottom).

Turn the crankshaft in the opposite direction of operation one-quarter revolution. Turn the crankshaft in the direction of operation until the impulse starter snaps. Turn the crankshaft slightly in the opposite direction of operation until the mark "S" on the flange is approximately 1 in. back of arrow on the bearing cap.

Raise the breaker point shield and place a 0.0015-in. feeler gage between the breaker points.

Turn the crankshaft slowly in the direction of operation, at the same time exerting a slight pull on the feeler gage with the fingers until the opening of the breaker points releases it. The mark "S" on the crankshaft flange should line up with the arrow on the front bearing cap. The gap between the breaker points should be 0.019 to 0.021 in. when fully open.

If the foregoing procedure discloses that the magneto timing is incorrect, return the crankshaft so that mark "S" on the flange is opposite the arrow on the bearing cap, loosen the magneto flange nuts, place a 0.0015-in. feeler gage between the breaker points, and rotate the magneto in the direction of operation (in the direction of the arrow on the back of the magneto) until the feeler gage is securely held by the breaker points. Then rotate the magneto in the opposite direction slowly until the feeler gage is released. Tighten the flange nuts and repeat the foregoing procedure as a check.

GUIBERSON DIESEL ENGINE

The only Diesel aircraft engine being built at present, and having C.A.A. approval, is the one built by the Guiberson Diesel Engine Co., Dallas, Tex. This is known as the A-10KO, from its piston displacement. This is a nine-cylinder, direct-drive, air-cooled, radial engine, which closely resembles any radial engine, the main dimensions being as follows:

Bore and stroke	$5\frac{1}{8} \times 5\frac{1}{2}$ in.
Compression ratio	14 to 1
Piston displacement	1,021 cu. in.
Rated power at sea level:	
Take-off, max. normal	310 hp. at 2,150 r.p.m.
Cruising power:	
With fixed pitch propeller at sea level	200 hp. at 1,850 r.p.m.
Crankshaft rotation (viewed from antipropeller end of engine)	Clockwise
Crankshaft propeller end	No. 30 spline
Over-all diam. of engine	$47\frac{1}{8}$ in.
Over-all length of engine	$33\frac{3}{8}$ in.
Fuel consumption, cruising	0.370 lb. per b.hp. per hr.
Oil consumption, max	0.015 lb. per b.hp. per hr.
Oil pressure, normal	85 lb. per sq. in.
Oil temperature (inlet)	145°F.
Weight, dry	653 lb.

The standard engine includes tachometer drive, fuel supply pump drive, generator drive, starter drive, a drive for mounting a vacuum pump or a propeller governor, exhaust flanges and gaskets, intercylinder, cylinder head and oil sump air baffles, propeller hub attaching parts, tool kit, and operator's manual. Thermocouple connections are obtainable at slight additional cost.

Among the advantages of the Diesel engine for aircraft is the safety against fire, largely because of the higher flash point of the fuel. The heavy oil used will not burn except when it is atomized and heated to 150°F. This removes the danger of fire from leaks in full tanks and fuel lines. Fuel cost and the longer flight range are also in its favor, the claim giving it from 35 to 50 greater mileage per gallon of fuel. There are no carburetors, spark plugs, magnetos, coils, high-tension wiring, and no shielding is necessary on account of radio interference.

Although the Diesel engine fires from the heat due to compression, the cylinder head temperature is only 250°F. This low temperature makes for a longer life to the exhaust valves and seats. Injection pumps and nozzles require great accuracy in workmanship but the nozzles have run over 5,000 hr. without adjustment. Another claim for this type of engine is the increase in service ceiling, due to more power which is available at the high altitudes.

SECTION X

CARBURETORS

BENDIX-STROMBERG INJECTION CARBURETOR

The repair of any carburetor should be attempted only by those having sufficient training in this work and the necessary tools and equipment.

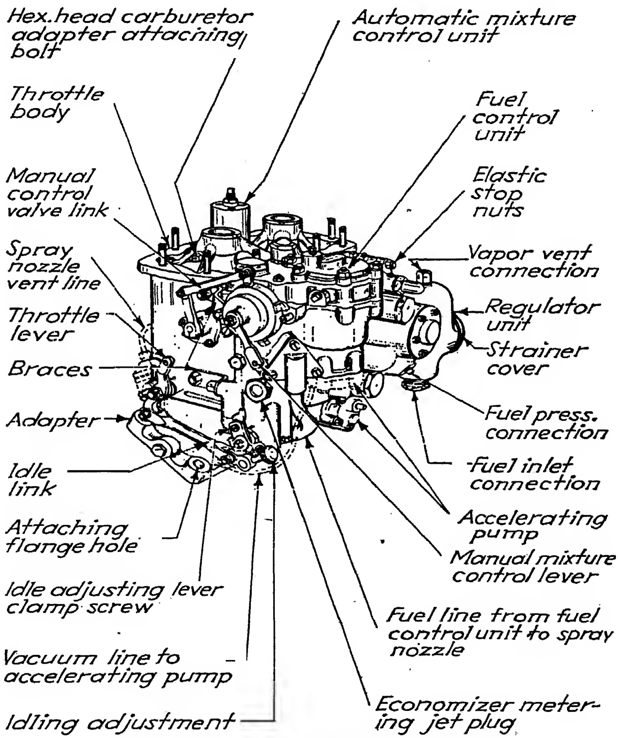


FIG. 1.—Bendix-Stromberg injection carburetor.

Every maker of carburetors furnishes instructions and suggestions that apply particularly to his type of carburetor. These should be carefully studied.

There are, however, general suggestions that apply to all carburetors. Those that follow are from the makers of the Bendix-Stromberg injection carburetor and apply especially to it.

The general procedure is to remove the carburetor from the engine, separate it into units, and disassemble, inspect, repair, and reassemble each unit independent of the other units. These are then reassembled into a complete carburetor and tested. The carburetor should then be set up on a flow bench and adjusted to conform with the data furnished, which exactly simulate engine conditions. When this is done, there is no need to make running tests on the engine test stand.

Overhauling should be done in a clean room that is free from dust, grit, chips, and moisture. All parts should be carefully handled, washed,

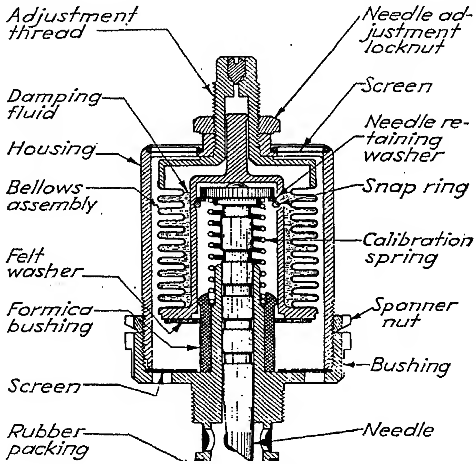


FIG. 2.—Automatic mixture-control unit.

inspected, and grouped by units. Parts from different units should not be mixed. *Do not employ carbon tetrachloride, or any cleaning fluids in which it is used, for flushing or cleaning the carburetor.* Its use will damage the diaphragms. Do not apply air pressure to the assembled carburetor or to subassemblies; high pressure will burst the diaphragms. Be sure to have the maker's instructions for the type of carburetor at hand and the specification sheets showing the proper settings.

The Stromberg injection carburetor is shown in Fig. 1, with its principal parts named. In disassembling, it can be taken apart in five units: regulator unit, fuel control unit, throttle valve body assembly, automatic mixture-control unit, and the adapter which carries the spray nozzles. These can be seen in Figs. 2, 3, 4, and 5.

Regulator Unit.—The regulator unit converts the air suction into a fuel metering force by means of a system of diaphragms operating the fuel poppet valve. These diaphragms are all assembled on a single stem to secure

a single, direct-acting element. This makes a somewhat complicated arrangement but eliminates wear and trouble in service. Great care must be taken in assembling these diaphragms to avoid perforating them with wrenches, screw drivers, or locking wires; to avoid twisting the center flanges relative to the outside bodies (this would leave wrinkles to chafe and interfere with free movement); to assemble parts centrally with all passage holes in the flanges and gaskets in proper alignment; to keep chips, dust, or

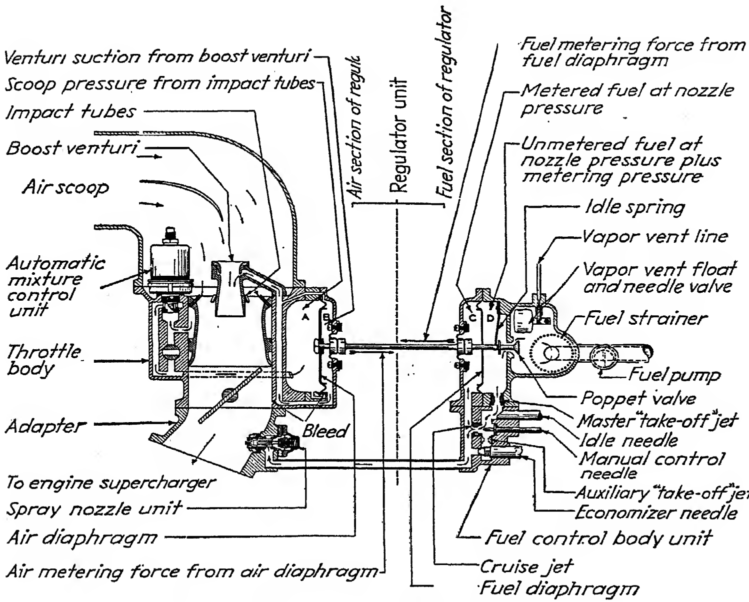


FIG. 3.—Diagram of Stromberg injection carburetor.

grit from getting into the folds of the diaphragms; to prevent diaphragms, plates, and spacers from turning on the stem when it is being tightened. Do not use carbon tetrachloride on the diaphragms. They may dry out somewhat stiff after soaking in gasoline, but they will become soft when they are put into service.

The regulator assembly is made up of four subassemblies, which are shown in Figs. 6 to 13. These parts are named and shown in their places or in proper order for assembly.

The parts should be cleaned in gasoline and carefully inspected. All drilled passages should be blown out with air *after the diaphragms have been removed.* All gaskets and packings should be replaced at each overhaul. This also applies to the small sealing diaphragms in the front and center bodies.

The Formica spacers and guide bushings should be inspected for cracks or chips. The guide bushings should be replaced if they are worn 0.036 in. loose or are scored.

The large fuel and air diaphragms should be checked for tears or other damage, and for loosening from their shields. If only slightly loose, they can be recemented with Neoprene cement, type 2. Questionable diaphragms should never be put into service. The idle spring assembly (Fig. 14) should be laid flat on a plate and checked for the dimension from the plate to the highest point of the radius at the fork. This should be

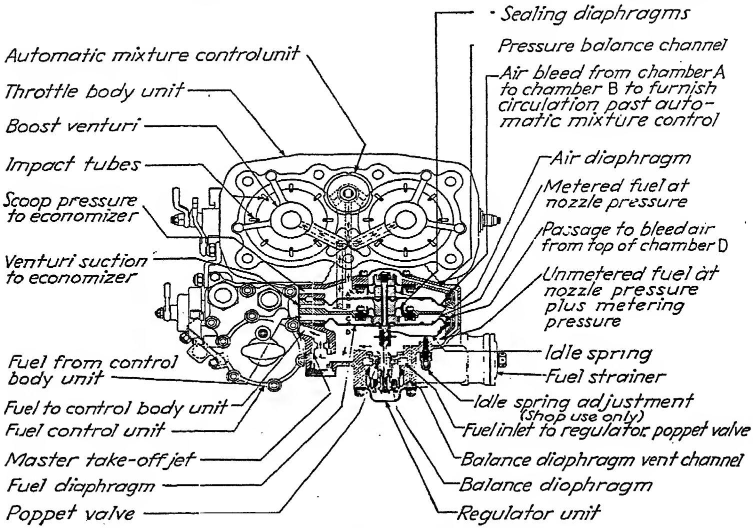


FIG. 4.—Sectional diagram of regulator unit.

$1\frac{1}{32}$ in. $\pm$ 0.010 in. Check the rivets to see that they are tight. This is shown in Fig. 14.

The end play in the joints of the regulator stem assembly should not exceed 0.015 in.

Check the Float Needle and Seat in the Vapor Separator.—Replace, if the seat is badly worn or if the guide portion is more than 0.012 in. loose. The clearance between the float bushing and the float fulcrum pin should not exceed 0.009 in.; the clearance in the float needle slot over the pin of the float assembly should not exceed 0.014 in.

The clearances of the parts of the various units are assembled in the table shown on page 353.

Figures 15, 16, and 17 show details of the mixture control, the assembly of the economizer diaphragms, and the completely assembled fuel control unit. Figure 18 gives the throttle body assembly. With these views and with all the parts named, a good mechanic without experience on this particular carburetor should have little difficulty in putting it together correctly.

These illustrations are so self-explanatory that detailed description seems unnecessary in most cases. They show the construction of the carburetor and its parts, and just where each part goes. Detailed information as to complete overhaul and testing procedure can be had from the makers of the carburetor that is in need of inspection and repair.

It should be remembered that the carburetor is a delicate mechanism on which the proper functioning of the engine largely depends. Without proper and dependable supply of fuel no engine can give its best performance, nor can it use its fuel to the best advantage. Airplane carburetors are much

Table of Clearances

	Min.	Desired	Max.
Throttle Body Assembly			
Clevis pin bushing in throttle stop lever	0.0005	0.001L*	0.005L
Control valve shaft in bushing	0.001L	0.002L	0.007L
Emergency full rich valve shaft link bolt in lever	0.0007L	0.002L	0.010L
Throttle shaft in bushing	0.001L	0.0015L	0.007L
Fuel Control Unit			
Enrichment valve stem in seat guide	0.001L	0.002L	0.008L
Regulator fill valve in seat guide	0.0015L	0.003L	0.010L
Mixture control shaft in bushings	0.001L	0.002L	0.007L
Camshaft in bushings	0.001L	0.002L	0.007L
Economizer needle in seat	0.001L	0.0025L	0.010L
Economizer needle slot over pins on forked lever	0.001L	0.002L	0.008L
Economizer lever over fulcrum pin	0.001L	0.002L	0.008L
Economizer stem bushing over lever pins	0.0005L	0.0015L	0.007L
Economizer Formica guide bushings in lever body	0.0095L	0.015L	0.036L
Idle needle valve in sleeve	0.0006L	0.0006L	0.002L
Idle needle valve pin in lever slot	0.0002L	0.003L	0.015L
Idle shaft in body bushings	0.0005L	0.0015L	0.007L
Idle lever over clevis pin bushing	0.0005L	0.001L	0.005L
Manual mixture control needle in inner bushing	0.0005L	0.001L	0.005L
Manual mixture control needle guide bushing in body	0.001L	0.0025L	0.010L
Manual mixture control needle adjusting nut slot over forked lever pins	0.001L	0.002L	0.010L
Manual mixture control shaft in bushings	0.0005L	0.0015L	0.007L
Regulator Unit			
Float fulcrum bushing over fulcrum pin	0.0015L	0.003L	0.009L
Float fulcrum bushing end play	0.006L	0.015L	0.032L
Float needle slot over float pin	0.002L	0.005L	0.014L
Float needle in seat	0.0015L	0.003L	0.012L
Guide bushings (Formica) in guides, front and rear	0.018L	0.021L	0.036L
Idle spring (Fig. 14) dimension "A"	1.021	1.031	1.041
Stem, end play	0.0015L	0.0015L	0.015L

* The letter L means "loose" by the amount shown.

more complicated and more delicate than those used on automobile engines, as can be seen from a study of the illustrations. The supercharger adds to the complications. The proper functioning of the engine is extremely important in the case of a plane, whether it be in use for transport or military purposes. As in all aviation work, extreme care in handling is most essential.

MARVEL-SCHEBLER CARBURETOR

The Marvel-Schebler aircraft model MA carburetor is of the updraft, plain-tube, fixed-jet type and is made up of two major units: a cast aluminum throttle body and bowl cover, and a cast aluminum fuel bowl and air entrance. It is made by the Marvel-Schebler Division of the Borg-Warner Corp., Flint, Mich. Its construction is shown in Fig. 19, in which all the principal parts are named.

Although no detailed constructions of the various parts of this carburetor are given, the instructions which follow will enable any good carburetor repair

man to handle the Marvel-Schebler without difficulty. The principles of operation of all carburetors are similar in many respects.

Operation. *Idle System.*—With the throttle valve slightly open to permit idling, the suction or vacuum above the throttle on the manifold side is very high. Very little air passes through the venturi at this time, and hence, with very low suction on the main nozzle, it does not discharge fuel. This high suction beyond the throttle, however, causes the idle system to function, as the primary idle delivery delivers into the high suction zone above the throttle. Fuel from the fuel bowl passes through the fuel channel power jet, and into the main nozzle bore, where it passes through the idle supply opening in

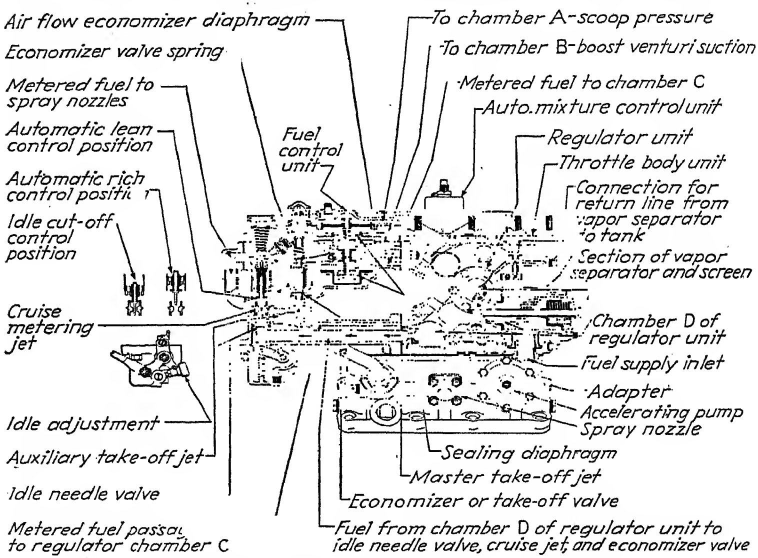


FIG. 5.—Sectional diagram of fuel-control unit—Stromberg.

the main nozzle through the idle fuel orifice in the idle tube where it is mixed with air which is allowed to enter the idle tube through the primary idle air vent and secondary idle air vent. The resultant rich emulsion of fuel and air passes upward through the idle emulsion channel where it is finally drawn into the throttle barrel through the primary idle delivery opening, subject to regulation of the idle adjusting needle, where a small amount of air passing the throttle valve mixes with it, forming a combustible mixture for idling the engine. The idle adjusting needle controls the quantity of rich emulsion supplied to the throttle barrel, and therefore controls the quality of the idle mixture. Turning the needle counterclockwise away from its seat richens the idle mixture to the engine; turning the needle clockwise toward its seat makes the idle mixture lean.

Idling, some air is drawn from the throttle barrel above the throttle valve through the secondary idle delivery opening and blends with the idling mix-

ture being delivered to the engine, subject to regulation of the idle adjusting needle. The secondary idle delivery begins to deliver idling mixture to the engine as the throttle is opened, coming into play progressively and blending with the primary idle delivery to prevent the mixture from becoming too lean as the throttle is opened and before the main nozzle starts to feed.

Metering.—All fuel delivery on idle, and also at steady propeller speeds up to approximately 1,000 r.p.m., is from the idle system. At approximately 1,000 r.p.m. the suction from the increasing amount of air now passing through primary and secondary venturi causes the main nozzle to start delivering; the idle system delivery diminishes, owing to lowered suction on the idle delivery openings as the throttle valve is opened for increasing propeller speeds, until at approximately 1,400 r.p.m. the idle delivery is prac-

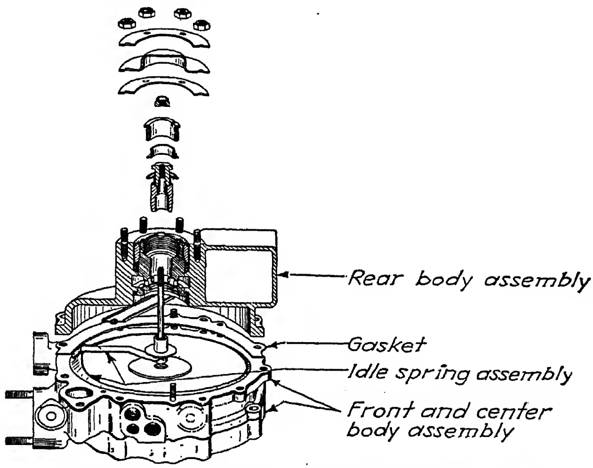


FIG. 6.—Regulator poppet valve disassembled—Stromberg.

tically nil, and most of the fuel delivery from that point on to the highest speed is from the main nozzle. However, the fuel feed at any full throttle operation is entirely from the nozzle. The idle system and the main nozzle are connected with each other by the idle supply opening. The amount of fuel delivered from either the idle system or main nozzle is dependent on whether the suction is greater on the idle system or the main nozzle, the suction being governed by the throttle valve position and engine load. The main nozzle feeds at any speed if the throttle is open sufficiently to place the engine under load, which drops the manifold suction. Under such conditions of low manifold suction at the throttle valve, the main nozzle feeds in preference to the idle system because the suction is multiplied on the main nozzle by the restriction of the venturi.

Main Nozzle.—The main nozzle is supplied with fuel which passes from the fuel bowl through the fuel channel. The fuel then passes upward through the nozzle bore where it is mixed with air drawn from the nozzle air vent and

nozzle bleed holes and is then discharged from the nozzle outlet as an air and fuel emulsion, into the mixing chamber. Air passing through the nozzle air vent sweeps fuel from the nozzle well and nozzle bore under very low suction and therefore satisfies any sudden demand for nozzle fuel delivery.

Adjustment.—If, after checking all other points on the engine, it is found necessary to readjust the carburetor, proceed as follows:

With the engine thoroughly warmed up, set the throttle stop screw so that the engine idles at approximately 350 r.p.m. Turn the idle adjusting needle

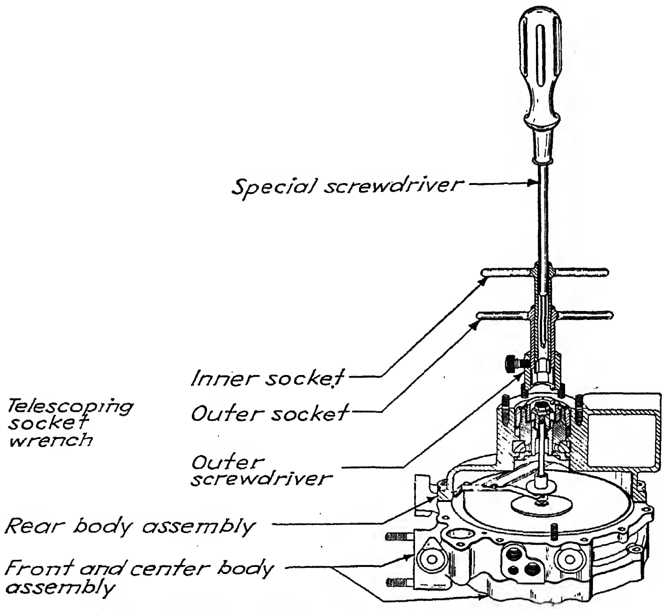


Fig. 7.—Regulator poppet valve assembled—Stromberg.

out slowly until the engine "rolls" from richness, then turn the needle in slowly until the engine "lags" or runs "irregularly" from leanness. This step will give an idea of the idle adjustment range and of how the engine operates under these extreme idle mixtures. From the lean setting, turn the needle out slowly to the richest mixture that will not cause the engine to "roll" or run unevenly. This adjustment will in most cases give a slower idle speed than a slightly leaner adjustment, with the same throttle stop screw setting, but will give the smoothest idle operation. A change in idle mixture will change the idle speed and it may be necessary to readjust the idle speed with the throttle stop screw to the desired point. The idle adjusting needle should be from three-quarter to one turn from its seat to give a satisfactory idle mixture.

Caution. Care should be taken not to damage the *idle needle seat* by turning the *idle adjusting needle* too tightly against the seat, as damage to this seat will make a satisfactory idle adjustment very difficult.

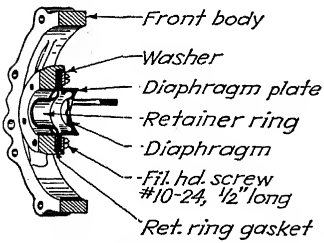


FIG. 8.—Front body assembly—Stromberg.

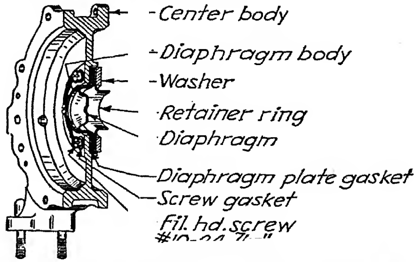


FIG. 9.—Center body assembly—Stromberg.

Float Height.—The float height is set at the factory and can be checked by removing the throttle body and bowl cover and float assembly and turning upside down. Proper setting of the two floats should measure 1 1/32 in. from the bowl cover gasket to the closest surface of each float. Be sure to check both floats to proper dimension, making sure that they are parallel to the bowl cover gasket.

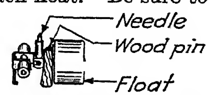


FIG. 10.—The float and needle—Stromberg.

Starting—Cold Engine.—The MA carburetor is designed to start a cold engine with the throttle stop approximately 3/32 in. from the throttle stop screw. With the throttle in this position, turn the engine over two or three times before the ignition is turned on. This will draw a finely emulsified mixture of air and fuel up through the idle system and then, if the ignition is turned on, the engine should start on the next turnover; with the

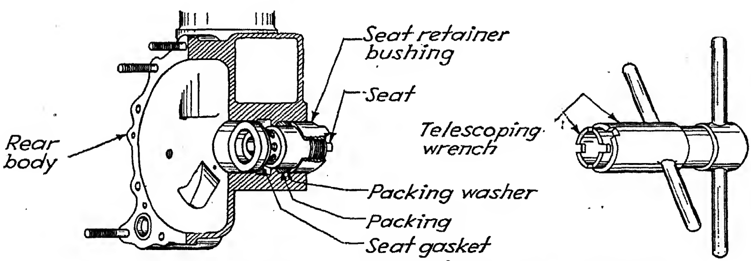


FIG. 11.—Rear body assembly and telescoping wrench used—Stromberg.

throttle stop 3/32 in. from the throttle stop screw, there should be sufficient throttle opening to keep the engine running. The carburetor is calibrated to give the richest mixture at this throttle opening; therefore a cold engine will run the smoothest with the throttle in this position. For this reason the engine should be allowed to warm up for several minutes before the throttle is opened further.

Starting—Hot Engine.—To start a warm or hot engine, pull the throttle stop against the throttle stop screw in the idling position. If the engine has just been shut off, turn on the ignition and the engine should start on the first turn; if the engine has been shut off for several minutes, it may be necessary to turn it over once or twice before turning on the ignition. A warm or hot

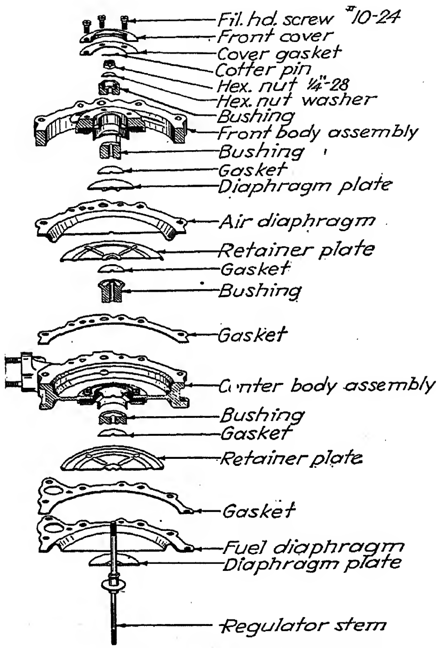


FIG. 12.—Parts of the regulator—Stromberg.

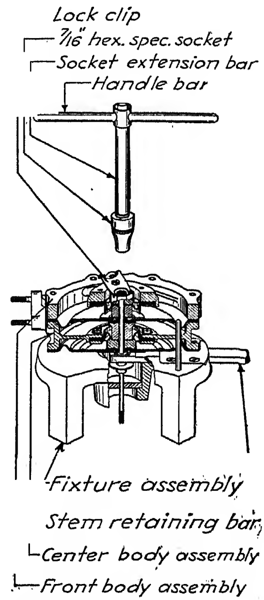


FIG. 13.—Front and center sections of regulator bled—Stromberg.

engine should start and continue to run with the throttle in the idling position.

Service Repair Instructions.—Remove all safety lock wires.

Remove the bowl cover screws.

Separate the throttle body and bowl cover assembly from the carburetor body and bowl assembly.

Disassemble the Carburetor Body and Bowl Assembly.—Using a small cold chisel, bend the prongs on the main nozzle lock gasket to permit the removal of the main nozzle. **Caution.** Do not distort the main nozzle assembly during this operation. Remove the main nozzle and the main nozzle lock gasket with the proper tools.

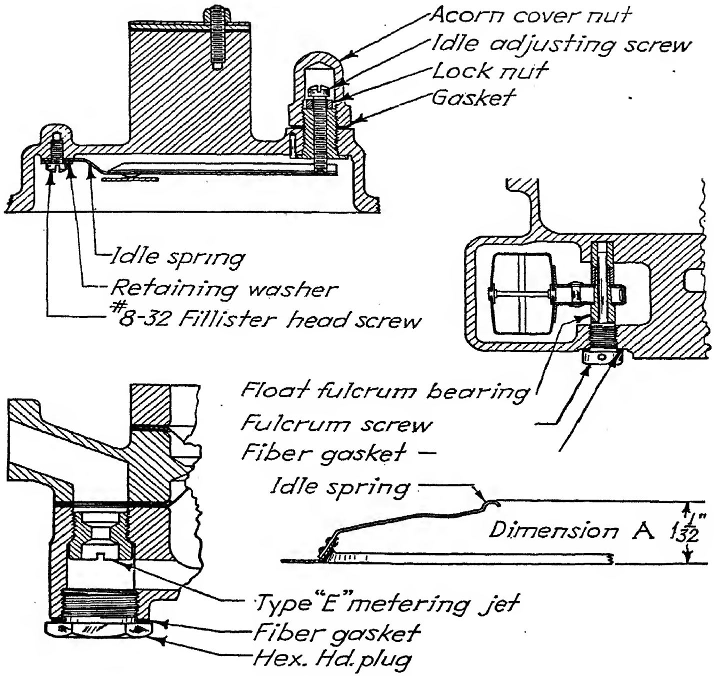


FIG. 14.—Details of carburetor parts—Stromberg.

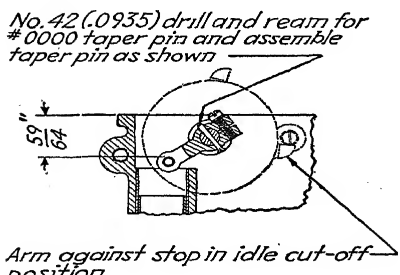


FIG. 15.—How the inside mixture-control lever is pinned to the shaft.

Remove the power jet, using a suitable screw driver. It is not always necessary to remove the power jet gasket. However, when this is necessary use great care in doing so, otherwise the gasket seat in the casting may be ruined, and this would necessitate replacement of the casting.

Remove the idle tube with a suitable screw driver.

Remove the bowl drain plug.

Disassemble the Throttle Body and Bowl Cover Assembly.—Remove the cotter key from the float lever shaft.

Remove the float lever shaft and the float and lever assembly.

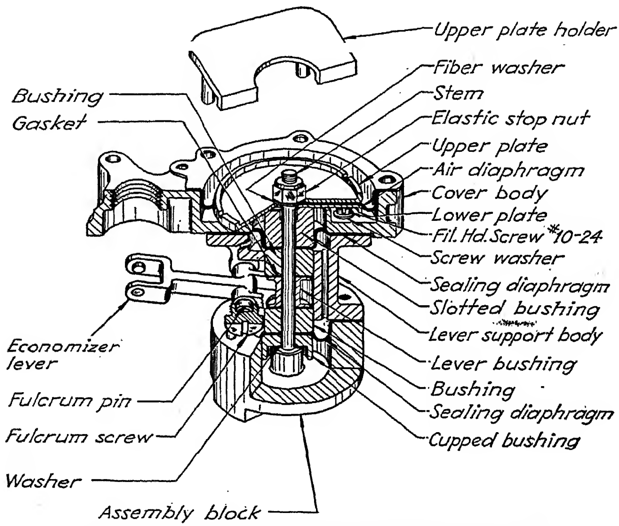


FIG. 16.—Assembly of economizer diaphragms—Stromberg.

Remove the float valve.

Remove the throttle body to bowl gasket.

Remove the float valve seat and float bracket by loosening the solder on these parts with a suitable soldering iron.

Remove the idle needle, and spring.

Remove the throttle stop screw and spring.

Remove the throttle fly screws and the throttle fly.

Remove the throttle opening spring cotter key and the spring.

Remove the throttle shaft bushings, using the tool provided for this work.

Remove the fuel inlet screen assembly with a suitable screw driver.

It should never be necessary to remove the venturi except under extreme circumstances, in which case use the proper tool.

Castings and parts should be thoroughly cleaned before reassembly. Do not use any metallic instrument (or wires) to clean jets, orifices, channels, or seats. The float and lever assembly should be tested for leaks by immersing

them in hot water (approximately 180 to 200°). If any bubbles appear while the floats are under water, they should be replaced.

Reassemble the Throttle Body and Bowl Cover Assembly.—If the venturi has been removed, reassemble the main venturi and primary venturi, making sure that the V points on the primary venturi arms line up with the component notches in the throttle body and bowl cover casting.

Install new throttle shaft bushings by using the throttle shaft bushing driver tool. Drive the throttle shaft bushing flush with the casting. Ream the throttle shaft bushings.

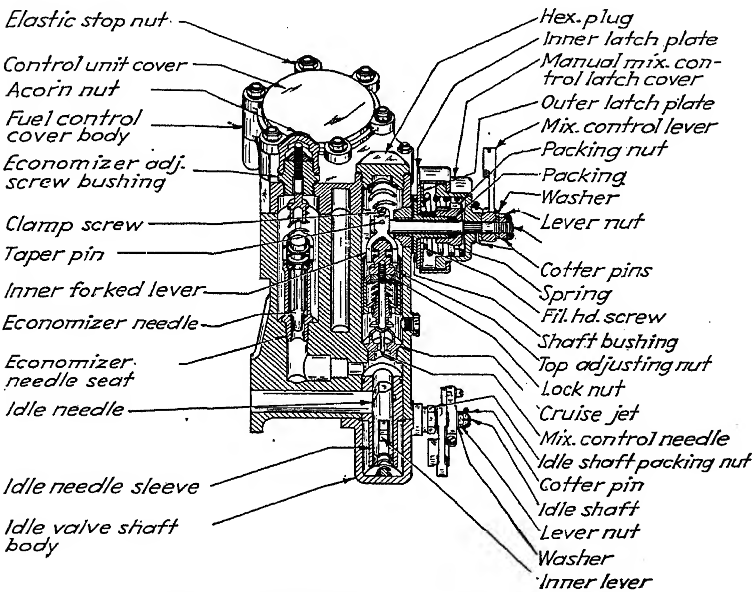


Fig. 17.—The assembled fuel control unit—Stromberg.

Insert the throttle shaft and stop assembly.

Reassemble the safety throttle lever spring and cotter key, being sure that it keeps the throttle fly in a wide open position. **Caution.** Give the spring only enough tension to open the throttle. Too much tension may cause the throttle to open while idling.

Reassemble the throttle fly by using new throttle fly screws. *Note:* The mark "T" on the throttle fly should be toward the top and on the side opposite from the idle adjusting needle. Do not tighten the throttle fly screws until the throttle fly has been properly positioned in the throttle barrel by closing the throttle fly. Clinch the throttle fly screws. Insert the throttle stop screw and spring. This must be done after fitting the throttle fly. Set the throttle stop screw so that the throttle fly is slightly open.

Reassemble a new float valve seat and gasket. After tightening the float bracket screws, solder the float bracket screws, float bracket, and float valve seat together, being careful that an excessive amount of solder is not used, which would restrict the free movement of the float lever.

Install a new float valve.

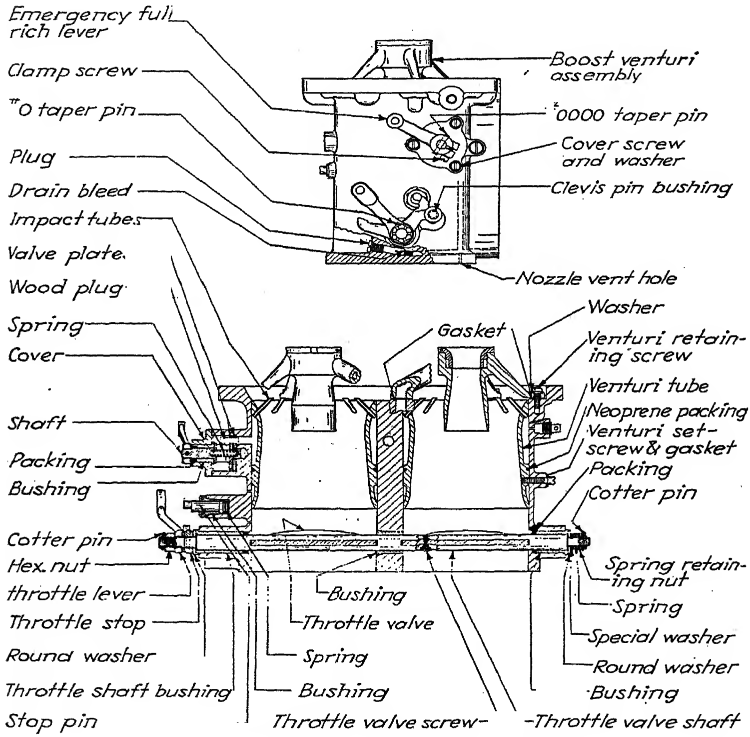


FIG. 18.—Assembly of throttle body—Stromberg.

Install a new bowl cover gasket.

Reassemble the float and lever assembly to the float bracket after having tested the metal floats for leaks.

The float height should be $1\frac{1}{32}$-in. from the surface of the bowl cover gasket to the nearest edge of the metal float with the throttle body and bowl cover assembly held upside down. Both floats should be set evenly and must operate freely in the fuel bowl.

Insert the float lever shaft and lock it in place with a cotter key.

Insert the fuel inlet screen assembly with a suitable screw driver, until reasonably snug.

Insert the idle needle and spring, being sure not to ring or groove the point against casting. If the idle adjusting needle point has been ringed or grooved, a new one should be used. For approximate setting, back the idle needle off one turn from its seat.

Reassemble the Carburetor Body and Bowl.—If the power jet gasket has been removed, replace it with a new one.

Insert the power jet.

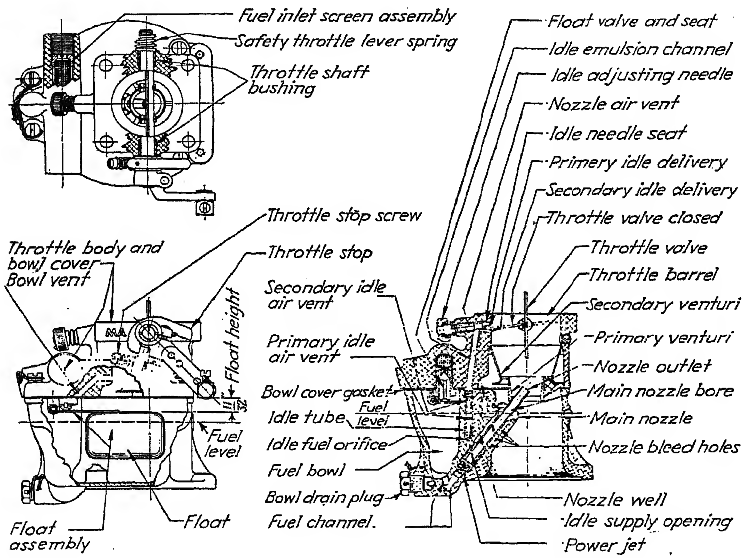


FIG. 19.—Construction of Marvel-Schebler carburetor.

Insert the main nozzle, using a new main nozzle gasket. Bend the prongs of the main nozzle gasket upward around the main nozzle hex. After using the proper tool tighten the prongs of the gasket against the hex of the nozzle with suitable pliers.

Insert the idle tube with the suitable screw driver, making sure it is reasonably snug. Do not force it on the seat.

Insert the bowl drain plug.

Reassemble the Throttle Body and Bowl Cover Assembly and Carburetor Body and Bowl Assembly.—Tighten the bowl cover screws and lock washers.

Lock all bowl cover screws and drain plug with safety lock wires.

Suitable tools, made especially for the purpose, should be available before carburetor repairs are attempted.

SECTION XI

MAGNETOS

The magneto is one of the vital accessories of any internal-combustion airplane engine, except those of the diesel type, in which the charge is ignited by the heat of compression. Magnetos have a permanent magnet field revolving between the pole pieces, as shown in the skeleton schematic illustration, Fig. 1, from the Scintilla Magneto Division of the Bendix Aviation Corp. This shows the two magnetos on a plane motor, one magneto being in outline; also a booster magneto to assist in starting the engine.

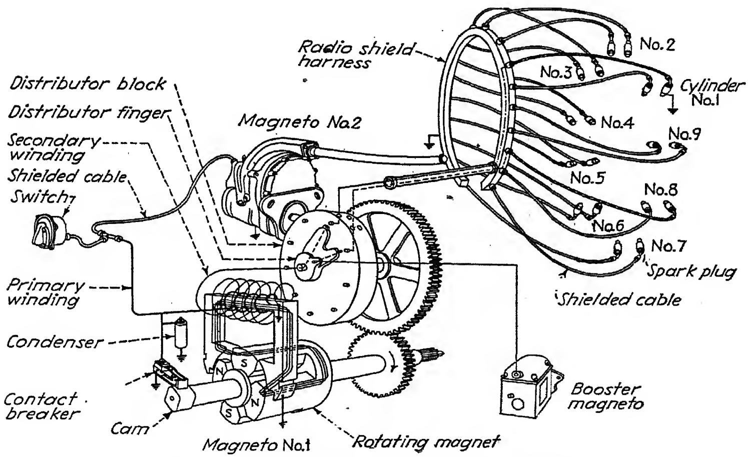


Fig. 1.—Skeleton diagram of Scintilla ignition system.

A study of this will show how the current is generated, how it is sent to different spark plugs by the distributor, and the various elements that go to make up the system. Following this are schematic diagrams that show the circuits of three of the Bendix-Scintilla magnetos (Figs. 2, 4, and 6). Details of these are seen in Figs. 3, 5, and 7.

As will be seen, the principles involved in these various designs are necessarily the same; only the details of construction are different. The illustrations and the accompanying titles make detailed description unnecessary. Since the similarity of the different designs makes it unnecessary to give more than a general outline of the methods of inspecting and checking these magnetos, only one type is considered. The suggestions are those of the makers.

Magnetos should be serviced only by those who have the proper tools and who are experienced in this line of work, as some of the parts are quite delicate.

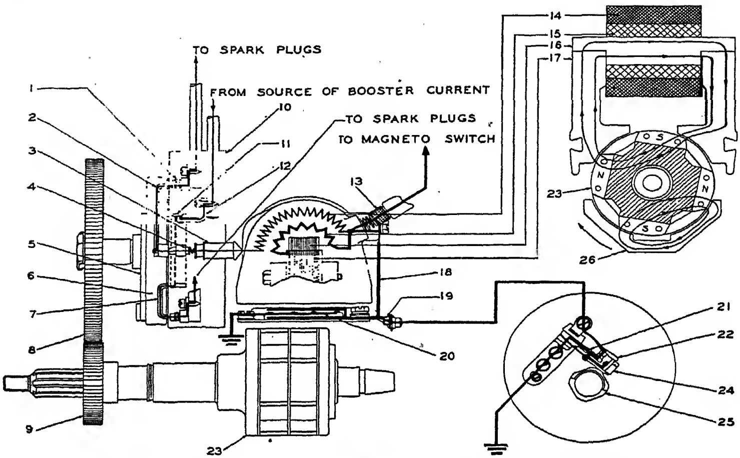


FIG. 2.—Diagram of Scintilla magneto types SF9L-2 and SF9LN-2.

1. Distributor-block electrode
2. Segment in distributor finger carrying secondary current
3. High-tension contact button
4. Carbon brush
5. Distributor-gear axle
6. Distributor finger
7. Segment in distributor finger carrying booster current
8. Distributor gear, large
9. Distributor gear, small
10. Distributor block
11. Collector ring, booster current
12. Insert, booster current
13. Ground-contact button
14. Secondary winding
15. Primary winding
16. Coil core
17. Pole shoes
18. Primary connector, coil to condenser
19. Primary connector, conductor to breaker
20. Primary condenser
21. Support, contact breaker
22. Spring, contact breaker
23. Rotating magnet
24. Cam follower
25. Breaker cam
26. Keeper, magnet poles

BENDIX-SCINTILLA MAGNETO

Disassembly and Inspection.—Remove the safety pin and the fastening screw, and take off the cover. Unfasten the lock ring and slotted nut, then remove the ground wire terminal screw.

Take out the two screws holding the radio shield assembly to the front end plate and lift this from the magneto. A little pressure toward the coil, at the top and the bottom of the assembly, will make it possible to lift this off. Loosen the two screws near the base of the radio shields that hold the distributor block. Take out the clamping screws that hold the halves of the shield together, and disengage them. If the electrodes are not worn enough to require replacement, clean their surfaces with fine *emery* cloth. A special socket wrench is provided for them. The Scintilla company supply tools for overhauling which should always be used.

The taps supplied by Scintilla for this purpose should be used when necessary to clean out the threads in the distributor block and also the tapped holes for the cable piercing screws. Place the distributor block in the radio

shield assembly and check the height of each electrode with the special gage provided for this purpose. If new electrodes are installed, it may be necessary to remove some of the material; if so, put the distributor block in the special adapter provided. This holds it securely while the electrodes are being machined to the right length. Examine all parts of the distributor

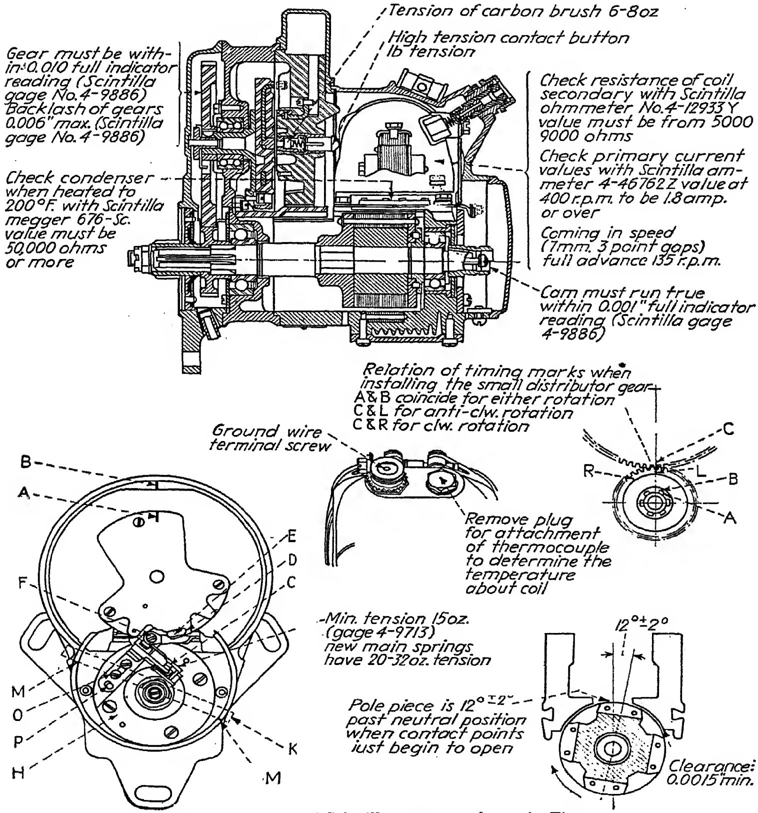


FIG. 3.—Details of Scintilla magneto shown in Fig. 2.

block for even small cracks. If there are any foreign particles in the cable holes, be sure the holes are clean before they are used again.

Contact button pressure is important. Press the button until the tip is 5/16 in. from the face of the distributor block. This should require between 3¾ and 4¼ lb. pressure. Compress the carbon brush to see if the spring is lively. The carbon brush and contact button must always move freely.

Be sure that either will come back to its original position under its own spring tension. If the carbon brushes stick or are broken, they may cause serious damage to the magneto as this would leave a gap in the secondary circuit within the magneto itself. Should high-tension current be allowed to jump a gap at this point continuously, the dielectric material might be burned away.

Should it be necessary to remove the contact button and carbon brush assembly, place a screw driver under the head of the contact button. Pad the part of the screw driver in contact with the distributor block. A slight

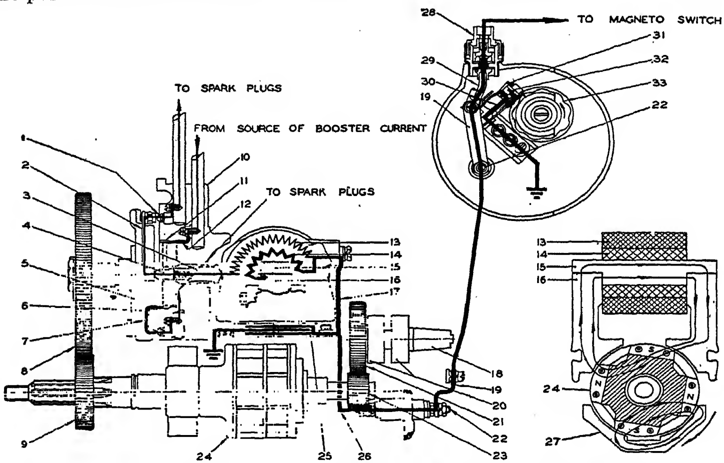


FIG. 4.—Diagram of Scintilla magneto types SF9L-4 and SF9LN-4.

1. Distributor-block electrode
2. Distributor-finger high tension segment
3. High-tension contact button
4. Carbon brush
5. Distributor-gear axle
6. Distributor finger
7. Booster segment
8. Distributor gear, large
9. Distributor gear, small
10. Distributor block
11. Booster collector ring
12. Insert, booster current
13. Secondary winding
14. Primary winding
15. Coil core
16. Pole-shoe extensions
17. Primary connector, coil to condenser
18. Camshaft
19. Connector to contact assembly
20. Camshaft bearings
21. Cam gear, large
22. Insulated post
23. Cam gear, small
24. Rotating magnet
25. Primary condenser
26. Primary connector, condenser to insulated post
27. Keeper, magnet poles
28. Ground terminal outlet
29. Connector, contact assembly to ground terminal
30. Support, contact breaker
31. Spring, contact breaker, main
32. Cam follower
33. Breaker cam

pressure on the screw driver will force out the contact button. With this out of the way, the carbon brush, spring, and sleeve can be taken out.

Contact Breaker, Cam, and Adapter.—Take out the two screws and remove the breaker cover. Take out the screw that fastens the primary connector to the contact point assembly. Take out the two screws holding the contact point assembly and remove it. Lift out the eccentric screw.

Check the main spring tension with the scale shown in Fig. 8. Be sure that the hook is under the main spring near the contact point *E*, Fig. 8. The tension should not be under 15 oz. for an old spring. If a new spring is installed the tension should be from 20 to 32 oz. The shims, shown in Fig. 8,

are used to line up the contact surfaces squarely between the points. The number of shims used also affects the main spring tension, which is decreased by the addition of shims and increased by removing them.

The contact points should be carefully examined for roughness or pitting and excessive wear. The points can be cleaned and polished by using the

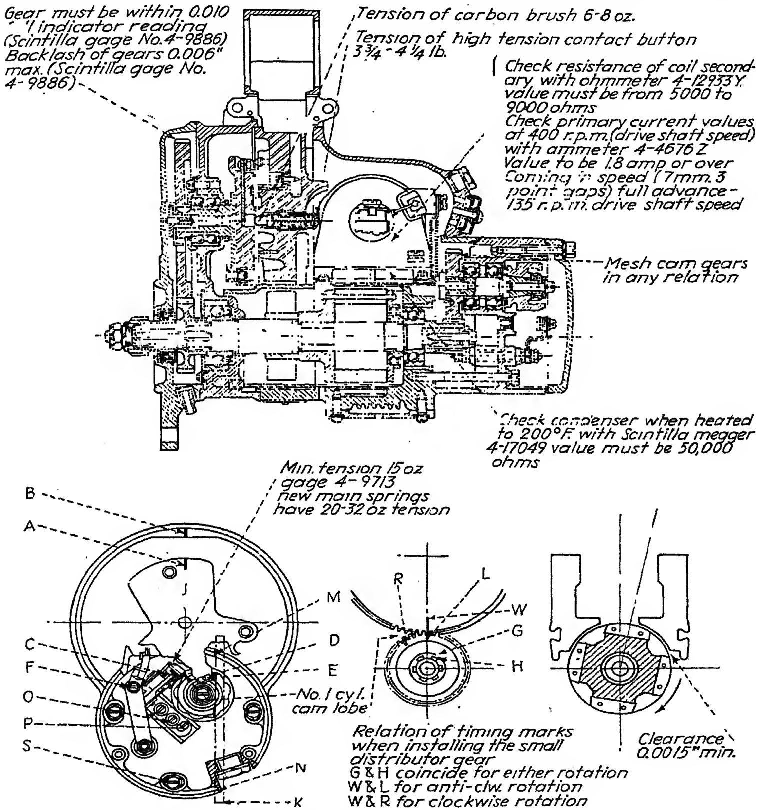


Fig. 5.—Details of Scintilla magneto shown in Fig. 4.

contact point block provided for this purpose. A special tool is also provided for assembling the parts of the contact point.

Use of the magneto causes wear on the top of the cam follower. This causes a small depression at the point where it lifts against the end of the main spring. The distance between the lowest point in this depression and the top of the spring on which the cam follower is riveted should be checked

at each overhaul. Unless this distance is $\frac{1}{32}$ in. or over, a new cam follower should be installed.

Take out the cam fastening screw, washer, bushing, and the two adjusting ratchets. Pull the cam with the cam puller provided for this purpose. Take out the three screws holding the adapter to the magneto housing and lift off the adapter assembly. Bend back the ear lock washer on the large cam gear screw, and remove the screw. While removing this screw, hold the camshaft with the special wrench.

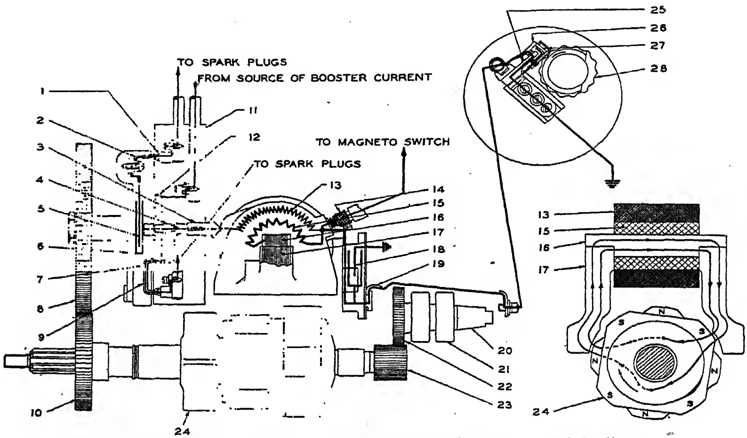


Fig. 6.—Diagram of Scintilla magneto types SF14L-3 and SF14LN-3.

1. Distributor-block electrode
2. Segment in distributor finger carrying secondary current
3. High-tension contact button
4. Carbon brush
5. Secondary condenser
6. Distributor-gear axle
7. Distributor finger
8. Distributor gear, large
9. Segment in distributor finger carrying booster current
10. Distributor gear, small
11. Distributor block
12. Collector ring, booster current
13. Secondary winding
14. Ground contact button
15. Primary winding
16. Coil core
17. Pole shoes
18. Primary condenser
19. Primary connector
20. Camshaft
21. Camshaft bearings
22. Cam drive gear, large
23. Cam drive gear, small
24. Rotating magnet
25. Support, contact breaker
26. Spring, contact breaker, main
27. Cam follower
28. Breaker cam

Take out the lock ring on the camshaft ball bearing. Take out the camshaft, large cam gear, both ball bearings, and the spacer that is between the two ball bearings. Check the teeth of the cam gears for excessive wear. Clean and repack the camshaft ball bearings with Keystone No. 44 grease or its equivalent.

The Coil.—Remove the two screws and clamps that secure the coil to the pole shoe extensions. Take out the two screws that hold the coil to the magneto housing. Take out the screw holding the flexible primary lead to the coil and lift out the coil. Take out the condenser, bushings, and primary leads by removing the four screws securing them to the magneto housing.

Examine the rubber housing of the coil for cracks. Make sure that all the inserts and screws are tight. The coil and condenser must then be tested electrically with special apparatus.

Front End Plate.—Remove the drive-shaft nut using a socket wrench for the nut and the special wrench to hold the drive gear. Take off the drive gear, using a puller if necessary. Remove the oil seal lock ring. Put 8-32 screws in the tapped holes and lift out the assembly and gasket. Remove the small distributor gear with a puller. Take out the four screws that hold the front end plate and mounting flange to the magneto housing.

Take out the three screws that hold the drive-shaft ball-bearing retainer, and remove the retainer. Put the special puller over the splined drive shaft, using its three screws in the tapped holes in the front end plate. With the puller evenly seated on the front end plate, turn the handle of the puller until the plate and mounting flange are disengaged from the rotating magnet and housing. Then remove the puller.

Remove the insulating plate from the front end plate. Disengage the mounting flange by taking out the screws that hold it to the front end plate. Bend back the four ear lock washers on the distributor gear axle hexagon screw. Remove the carbon brush and take out the screw, using a socket wrench and gear holder. Use a drift on the end of the distributor gear axle and tap with a light hammer until the axle is disengaged from the distributor gear and ball bearing. Remove the Woodruff key from slot in distributor gear. Disengage the axle and distributor finger by removing the three screws that hold it.

Remove the distributor gear axle ball-bearing retainer from the front end plate by taking out the screws. Drive out the distributor gear axle and drive-shaft ball bearing with the drifts provided for this purpose.

Examine the distributor finger and insulating plate for possible cracks. *Do not attempt to remove the secondary condenser sealed in the distributor finger*, but make sure that the screws securing the condenser cover plate are tight. Clean the high-tension segment on the distributor finger and remove any pitting. If the high-tension segment is worn badly or is burned, replace it with a new one. The same applies to the oil seal washer in the oil seal assembly. Check all gears for wear or burrs on the teeth. Clean and repack the ball bearings as mentioned before.

Magneto Housing and Rotating Magnet.—Remove the rotating magnet from the housing with the proper puller. Remove the screw that secures the small cam gear and take out the small gear with the puller. Take out the breaker end ball bearing with the puller; this bearing is of the sealed type and cannot be inspected or repacked. This makes it advisable to replace this bearing at the end of 1,000 hr. of service.

The order of reassembly is substantially the reverse of that for taking the magneto apart. However, many parts have press fits, and the proper tools must be used as a means of eliminating all possibility of damage.

The internal timing of the magneto is of the greatest importance. Timing marks are provided on the distributor gears, which must be meshed in the correct relation corresponding to the operating rotation of the magneto. Also, the breaker cam and contact points must always be set so that when the magnet is at the specified number of degrees past neutral with the distributor finger timing marks lined up, the contacts are just opening and the cam is lined up with the timing marks on the breaker end of magneto.

Timing to the Engine.—Before installing a magneto to an engine, make sure that it has been properly checked and inspected.

Turn the engine crankshaft in the direction of normal rotation until the timing disk pointer on the engine indexes with the timing disk set for the full advance firing position of cylinder 1.

Remove the main cover, breaker cover, and distributor block. Turn the magneto drive shaft until the timing mark (A, Fig. 3, 5, or 7) on the distributor finger is approximately opposite the timing mark B on the inside of the front end plate when a straightedge K placed on the step cut in the cam coincides with the timing marks M at the breaker end of the magneto hous-

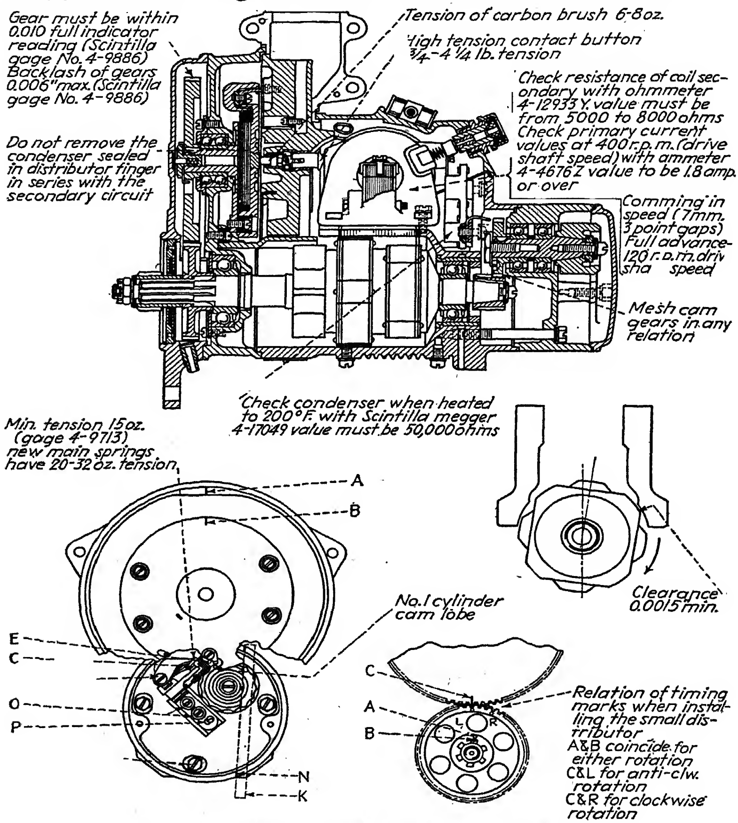


Fig. 7.—Details of Scintilla magneto shown in Fig. 6.

ing. At this position, the high-tension electrode D on the distributor finger will be opposite the distributor block electrode E for firing cylinder 1. Install the magneto to the engine in the foregoing relation but do not tighten the cap screws or nuts to the extent that further adjustment cannot be made.

When the exact timing is to be made, all adjustments must be made at the drive end and *not by altering the adjustment of the contact points.*

Make adjustments by turning the magneto through the angle provided by the slots in the mounting flange so that the contact points just begin to open when a straightedge K placed on the step of the cam coincides with the timing marks M at the breaker end of the housing. It may be found that timing mark A on the distributor finger is not exactly opposite the timing mark B on the inside of the front end plate after making the final adjustment by having the straightedge K on the cam coinciding with the timing marks M. However, any slight variance of the distributor finger timing mark A will not affect the operation of the magneto as this is merely used to locate the approximate firing position of the magneto for cylinder 1.

For synchronized spark requirements, the breaker contacts on each magneto must open simultaneously. To check this, place a 0.0015-in. feeler between the breaker contacts. When the shim stock can be released with a slight pull as the crankshaft is turned slightly, the breaker contacts are just beginning to open. When the synchronization has been made, secure the magneto firmly by tightening all cap screws or lock nuts.

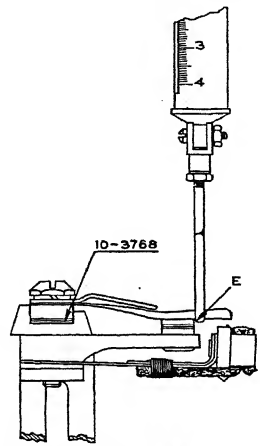


FIG. 8.—Checking spring tension of breaker.

For staggered spark requirements, one magneto will fire later than the other. Install and time one magneto in the same manner as explained for synchronized sparks. Then turn the engine crankshaft until the piston of cylinder 1 is in the correct position for the staggered spark requirements and install the other magneto in the manner followed for the first magneto.

Wiring.—Remove the cable piercing screws from the distributor blocks to avoid any possibility of the high-tension cables not being fully seated in the base of the cable holes.

Insert the spark-plug cable for cylinder 1 into the distributor block cable hole marked "1" and then secure it with the cable piercing screw. Be sure that the piercing screw is tight. Place the spark-plug cable for the next cylinder to fire into the distributor cable hole marked "2," etc. The numerals on the distributor block denote the serial firing order of the magneto and have no bearing whatsoever on the engine firing sequence. It is recommended that the part of the cable that is inserted in the distributor block cable holes be treated with talcum powder to prevent its fusing to the walls of the distributor block cable holes. Connect the cable from the booster source to the distributor block cable hole marked "B," and secure it with a cable piercing screw. A lock washer is not required beneath the head of this piercing screw. In the magneto not used for booster starting, see that a lock washer is used with the cable piercing screw in the distributor block cable hole marked B.

Before installing the radio shields, it is recommended that the connections be checked for any short or open circuit and to ascertain whether or not the cables lead to the proper cylinders from the magneto. Either a buzzer or light system or a booster magneto can be used. When using a buzzer or light system, touch the distributor block electrode with one point and the spark-plug end of the cable for the proper cylinder with the other. The

circuit is complete when the buzzer gives a signal or the lamp lights. If the circuit is not complete, check for a possible open circuit or wrong connection of the cable. To check for a short circuit due to faulty insulation of the cable, a booster magneto is used. The high-tension terminal of the booster magneto is connected to the distributor block electrode. The spark-plug end of the cable is held about ¼ in. from a grounded object. If no spark occurs, check the cable for faulty insulation.

Install the radio shields to the distributor blocks. Allow enough slack in the cables to prevent extreme sharp bends. Install the radio shields, distributor blocks, and main covers on the magnetos.

AMERICAN BOSCH MAGNETO

The American Bosch SF14LU-6 magneto is a 14-cylinder, fixed ignition, eight-pole, three-bolt, flange mounted polar inductor-type magneto of counterclockwise rotation, driven direct through a splined coupling. The magneto drive shaft which turns at seven-eighths engine speed rotates the 14-lobe compensating breaker cam at one-half engine speed through a 1¾ to 1 gear ratio between the magneto and breaker camshafts. It is radio-shielded and, complete with radio shield and drive member, weighs 17¾ lb. Figure 9 shows its construction and has the parts numbered.

The coil (15), magnet (42), and breaker (39) are stationary. The 14-lobe compensating, automatically lubricated cam (35) is mounted on the shaft of the distributor gear assembly (30). The distributor block electrodes are so spaced as to be suitable for high-altitude performance.

The inductor rotor (2) is mounted on the drive shaft and consists of four laminated sectors which, as they rotate, alternately provide eight distinct paths through the coil core from the poles of the stationary magnet (42). This gives eight reversals of flux per revolution of the inductor rotor (2), producing eight ignition sparks when the primary circuit is interrupted accordingly.

Magneto Housing.—The magneto housing (1) and three-bolt mounting flange, having a 3-in. pilot, are die-cast integrally of a high-pressure aluminum alloy. Two laminated pole shoes are cast in the magneto housing (1) and the coil (15) with laminated core is mounted on the extensions of these pole shoes. There are also two intermediate laminated pole shoes (P and P') cast in the magneto housing (1) and the extensions of these pole shoes terminate across the poles of the permanent magnet (42).

Inductor Rotor.—Four separate and laminated pole sectors are cast axially to the rotor shaft, which is supported by ball bearings on each end. The bearing (5) on the drive end is held in a fixed position, thereby preventing axial movement of the inductor rotor (2). The bearing (108) on the other end floats in the gear housing (49), and the outer raceway is kept from turning by the retaining spring (112). The drive-shaft end is splined to accommodate a drive coupling (12) which is secured with a recessed plain washer (11), lock washer (8), castle nut (10), and cotter pin (9).

The permanent magnet is stationary and is held in position by a special, self-locking Dardelet setscrew (55). The pole ends of this magnet make contact with pole shoe extensions (P and P') in magneto housing (1). This magnet is made from a special alloy known as Alnico.

Coil Assembly.—In the high-tension coil (15), the primary and secondary are wound, taped, and impregnated directly on its laminated core. This permits more copper and insulating material for a given space and tends to reduce the temperature rise of the coil.

The primary lead (82) from the coil (15) to the live side of breaker (39) can be uncoupled without the use of a soldering iron. This permits an easy hookup with an electrical timing indicator.

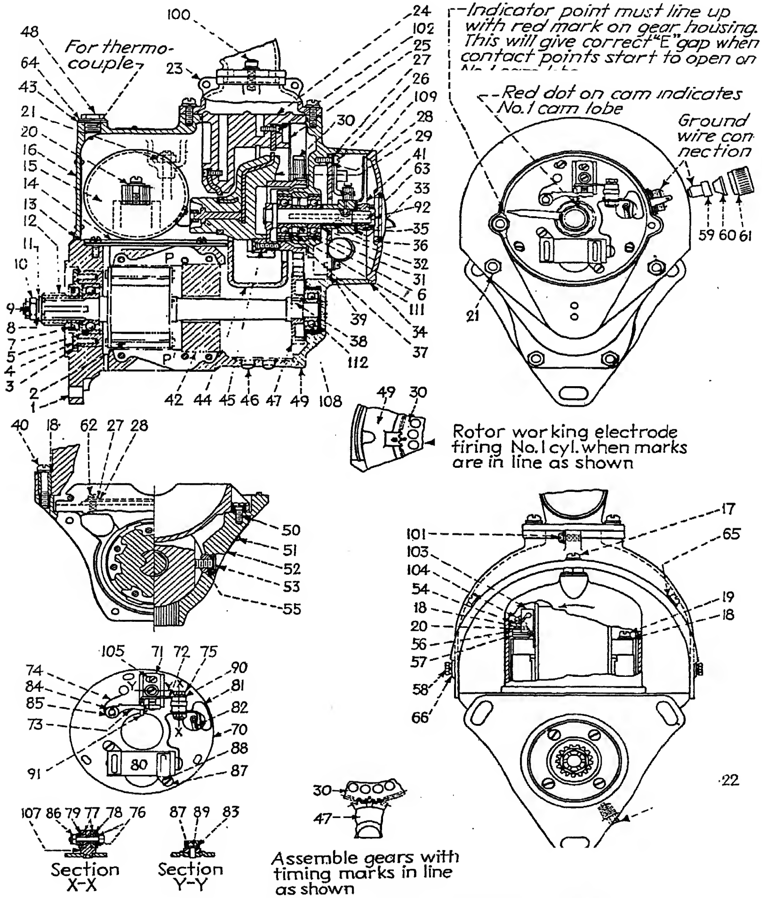


FIG. 9.—Details of American Bosch type SF14LU-6 magneto.

The circuit between the secondary coil terminal to the distributor rotor (29) is accomplished by mounting a ring and bracket assembly (106) to the coil terminal. The distributor rotor (29) has a protruding electrode extend-

ing into this ring. No physical contact is made. The circuit is made by a rotary jump spark.

A high-voltage blocking condenser is incorporated in series with the secondary winding within the coil (15), so the direct-current resistance of the secondary winding cannot be measured (see Testing and Performance, page 382).

Breaker Assembly.—The breaker (39) consists of

1. A slidable bracket (71) positioned between guides on the breaker plate (70), on which the grounded platinum-iridium contact point is mounted. This bracket is adjusted by an eccentric-headed stud (105) and is locked by screw (89).

2. A pivoted cam follower assembly (73), whose independent spring (74) holds the heel of the follower in contact with the contour of the 14-lobe cam (35).

3. A breaker spring assembly (72) includes the moving and live platinum-iridium contact point mounted on an insulated stationary terminal post. To this are connected the primary cable (82) of the coil (15), the live side of the primary condenser (80), and the short-circuiting spring (81). An oil guard mounted on the cam follower protects the breaker contact points.

Distributor Block.—Distributor block (24) is in one piece, of heat-resisting composition. Stainless-steel piercing screws (102) are used to secure all high-tension cables. The distributor block (24) is also provided with a booster connection which makes jump spark connection with the booster collector ring molded in the nose of the distributor rotor (29).

Distributor Rotor.—The distributor rotor (29) is molded in one piece of heat-resisting material, having two main distributing electrodes and two booster electrodes. The two booster electrodes are used in connection with an outside high-tension ignition source for starting purposes.

Radio Shielding.—In order to suppress disturbances caused by electrostatic waves radiated by the ignition system, the entire magneto, including the primary circuit within the breaker housing, is completely enclosed in metal housings or radio shields.

Fourteen-lobe Compensating Cam.—In all radial engines of conventional master rod design, the travel of each piston, with the exception of the master rod piston, is a few degrees either early or late in relation to the crank pin.

The 14-lobe cam (35) used in the SF14LU-6 has lobes so spaced as to compensate for the normal irregular angular position of each link rod in relation to the master rod. This ensures each cylinder's firing with its piston at the desired advance position. A reservoir (63) of oil located in a hole in the shaft of the distributor gear assembly (30) feeds oil to the cam surface in minute quantities. The oil in the reservoir (63) and the restrictor plug (92) is sufficient to last between major overhauls.

Timing and Installation

Internal Timing.—Both gears are in correct mesh when the white mark on distributor gear (1) is positioned between the two red marks on the inductor rotor gear (47) in Fig. 9. This can be observed through the hole in the gear housing (3) in Fig. 9.

The rotor working electrode is in position to fire cylinder 1 when the white mark on the distributor gear (30), on the side nearest the coil, is in line with the white mark (on red pad) on the inner face of the gear housing (3). When both sets of timing marks, as described above, are in line, lobe 1 of the com-

pensating cam, indicated by the red dot, is about to open contacts for firing cylinder 1.

Hold the pulley so that the timing indicator points to the red line on the side of the gear housing. At this position, lobe 1 of the compensating cam should start to open contacts. With the electrical timing indicator, provided for this purpose, connected to live contact and ground, adjust the breaker plate assembly until the instant the light goes out. At this position, secure the breaker plate assembly.

Important: The breaker contact point opening is adjusted to 0.009 to 0.010 in. on the special fixture. This corresponds to an "E" gap of 2.0 to 2.5 mm. on cam lobe 1 when the timing indicator registers with the mark on the gear housing.

Mounting Magneto to Engine.—Bring the piston of cylinder 1 to advance firing position required on the compression stroke. (Consult engine manufacturer's service bulletin which explains engine reference marks, indicating this position with reduction gearing removed or assembled.)

Remove the radio shield, dust cover, distributor block, and breaker cover. Turn the magneto shaft until lobe 1 is about to open the contact points. (Lobe 1 is marked by a red dot on the face of the cam.)

Hold the cam in this position by pressing the fingers against the distributor gear (1) and mount the magneto on the engine by means of the mounting studs. These must be approximately in the center of the magneto mounting flange slots. If the splines of the magneto coupling will not mesh with the splines of the engine drive in this position, remove the coupling from the end of the magneto drive shaft and turn to a position where the coupling will readily mesh with the internal spline on the engine drive.

After determining this position, remove the magneto and secure the coupling with a recessed plain washer, lock washer, castle nut, and cotter pin and install the magneto on the engine.

Note: It is important that when the magneto is mounted on the engine, the mounting studs be as near the middle of the flange slots as possible. When both magnetos have been mounted, tighten up the holding nuts just enough to hold the magnetos firmly against their mounting brackets, but loose enough so that they may be moved in their flange slots for final accurate timing adjustment (synchronizing) to the engine.

Final Timing to Engine.—The SF14LU-6 magneto is of the fixed ignition type; therefore, all working sparks delivered are advance sparks. A retarded spark for starting purposes is obtained by means of a booster system incorporated in the magneto.

The source of current for the booster system may be a booster magneto or a battery and vibrator coil arrangement connected to the booster terminal of magneto.

For synchronized sparks of both magnetos, both sets of points must open simultaneously. This can be done either by the "feeler gage method" or the "electrical method."

Feeler Gage Method (Reduction Gearing Assembled).—Put the engine in proper position, as described under Mounting Magneto to Engine above, on this page.

Turn the engine in the clockwise direction until the breaker points have closed. Insert 0.001-in. feelers between the breaker contact points. Turn the engine in a counterclockwise direction by very gradually jarring the propeller blade with the hand until a slight pull on the feelers releases them.

Both feelers should release at the same time and should require equal efforts of pull. At these magneto settings, the engine timing reference marks must register. When both magnetos are perfectly synchronized in this way, tighten the mounting stud nuts firmly and secure them with safety wire.

Connect the high-tension cables. The spark-plug cable for cylinder 1 is inserted in the distributor block cable hole marked "1" and secured with a cable piercing screw. Insert the cable for the cylinder next to fire, according to the firing order, into the distributor block cable hole marked "2," etc. *Note that the numerals on the distributor block indicate the firing order of the magneto only and must not be construed as the firing order of the engine.*

Replace the breaker cover, the distributor block, the dust cover, and the radio shield.

Electrical Method (Reduction Gearing Assembled).—With the engine in proper position, as described, proceed as follows:

Uncouple the primary lead of the coil from its terminal block, located on the left side of the coil facing the drive shaft. Connect the lead that comes from the live side of breaker to the electrical timing indicator, one side of which must be grounded.

Move the magneto in a counterclockwise direction in the slots of the magneto flange, until lobe 1 of the breaker cam starts to open the contact points of the breaker. This position is indicated at the instant the signal lamp of the electrical timing indicator goes out.

Follow the same procedure with the second magneto on the same engine. To ensure that both magnetos are synchronized, that is, the sparks of both magnetos occurring at the same instant for the same cylinder on lobe 1, both signal lights must go out at the same time. When both magnetos are synchronized, tighten the mounting stud nuts firmly.

Recheck the timing of both magnetos to the engine. Turn the engine in the counterclockwise direction by very gradually jarring the propeller blade with the hand until both signal lights go out. At these magneto settings, the engine timing reference marks must register. If the signal lights do not indicate synchronization with the engine timing reference marks, the magnetos must be moved slightly in their flange slots until synchronization is obtained. Tighten the mounting stud nuts and secure them with safety wire.

Connect the high-tension cables. The spark-plug cable for cylinder 1 is inserted in the distributor block cable hole marked "1" and secured with a cable piercing screw. Insert the cable for the cylinder next to fire, according to the firing order, into the distributor block cable hole marked "2," etc. Note that the numerals on the distributor block indicate the firing order of the magneto only and must not be construed as the firing order of the engine.

Replace the breaker cover, the distributor block, the dust cover, and the radio shield.

Disassembly and Inspection

These magnetos are readily disassembled by an experienced man. The parts should be removed in the following order: radio shield; dust cover, and breaker cover; distributor block; coil assembly; breaker assembly; distributor rotor; gear housing (3); inductor rotor assembly; and magneto frame.

Metal Parts.—All metal parts must be washed in clean gasoline and dried with compressed air. All parts must be free from chips and foreign material. Examine the magneto housing, gear housing, radio shield, and dust cover for cracks, loose inserts, and studs. Inspect all tapped holes.

Insulations.—All insulations, such as the distributor block, distributor rotor, apron, insulation plate, coil, insulation bushings, and washers must be cleaned with oily cloth and wiped dry with a clean cloth.

Coil Assembly.—Examine the coil for cracked end plates and check soldered connections.

Distributor Block.—Examine and clean cable holes and electrode surfaces; inspect for cracks.

Ball Bearing and Oil Seal.—Clean all ball bearings in an approved cleaning solution and replace all rough, loose, or worn bearings. Pack the bearings with high-temperature grease American Bosch U.S. 508 or equivalent.

Replace the oil seal if it shows evidence of excessive wear or leakage.

Gears.—Remove the restrictor plug and examine both the distributor gear assembly and rotor gear for burrs, excessive wear, or other defects. Clean the oil reservoir with approved cleaning solution.

Breaker Assembly.—Thoroughly inspect and clean all component parts of the breaker assembly. If the bakelized linen cam follower of the bearing hole of the cam follower lever is worn, replace it with a new lever assembly. Test the primary condenser on an approved condenser tester at 200°F.

Dressing of Contact Points.—Examine both contact points for evidence of wear. Extreme care must be exercised in dressing points to ensure a flat, square, and smooth surface. Use the special tool for this purpose.

Reassembly.—1. Place the breaker plate on the breaker assembly fixture and secure it by means of the three fastening screws, lock washers, and plain washers.

2. Mount the contact bracket with point and secure it to the plate by inserting a screw and lock washer through the cup-shaped breaker spring stop.

3. Assemble to the fastening bolt, the lock washer, spacing washer, contact spring with point, spacing washer, three shims, and insulation plate. Assemble these parts to the supporting post. Now assemble the insulation plate to the fastening bolt, and secure the assembly to the supporting post by means of the square nut.

4. Fill the groove in the cam follower lever supporting post with U.S. 508 grease. Assemble the cam follower lever and secure it by means of the plain washer and cotter pin. Assemble the follower lever spring.

Point Adjustment.—1. Shift the contact spring with the point (72) (Fig. 10) in its elongated hole until both contact points are in perfect alignment. Securely tighten the assembled parts on supporting post (107).

2. Adjust the contact point opening to 0.009 to 0.010 in.

3. Check the tension of the contact spring with the point (72), using the spring scale (Fig. 10). *Tension must be* 19 *to* 24 *oz. at the instant the points open.* Check with electrical timing indicator.

For spring tension above 24 oz., decrease by adding one shim (78); for spring tension below 19 oz., increase the tension by removing one shim (78). In adding or removing a shim (78), all parts on the fastening bolt (75) must be removed from the support post (107) and reassembled in their proper sequence, outlined in 3, under Reassembly. Readjust the contact points as outlined in 1 and 2 and recheck the tension.

4. Check the cam follower lever spring tension, using the spring scale as in Fig. 11. *Tension must be* 18 *to* 22 *oz. at the instant the top of the cam follower touches the contact spring with the point* (72).

5. Check the clearance between the top of the cam follower and the contact spring with the point. This must not be less than 0.017 in.

Completing the Assembly.—1. Fasten the condenser (80) to the breaker plate (70) by means of the fastening screw (88) and lock washer (87).

2. Assemble the short-circuiting spring (81), cable assembly (82) and condenser lead on the fastening bolt (75), and secure the nut (86), using the tool provided. The breaker assembly (39) should be removed from the breaker assembly fixture and is ready for installation on the magneto.

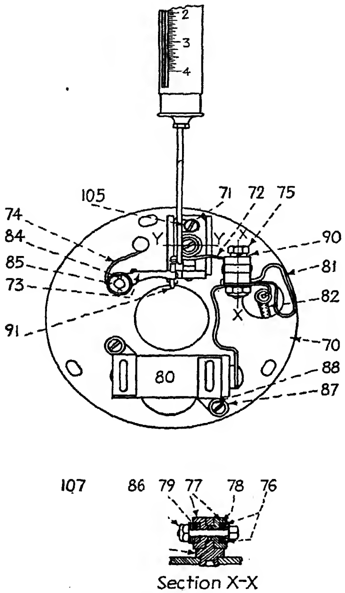


FIG. 10.—Checking alignment of contact points.

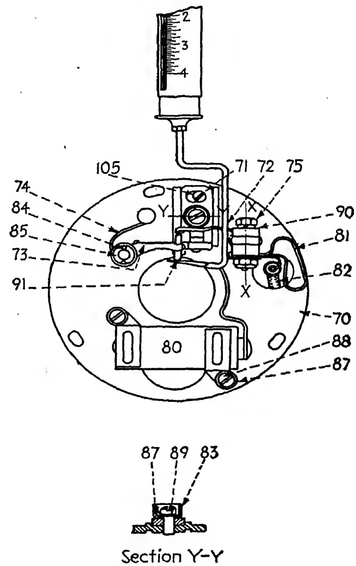


FIG. 11.—Measuring tension of follower lever spring.

Reassembly

Gear Housing Assembly (49).—Mount the outer bearing race locking key in the gear housing (49) and secure it with a spring ring (110). Locate the slot in the bearing (37) which is packed with U.S. 508 grease with the locking key (111), so the slot in the bearing will engage the key when the bearing is pressed in position. Assemble the spacer (31) in the gear housing (49). Mount the bearing (6), following the same procedure as outlined, to align the slot in the bearing with the key. Insert the distributor gear assembly (30) through the bearings (6 and 37).

Note: Exercise care so that the shaft engages the spacer (31).

Magneto Housing (1).—Remagnetize the magnet (42) separately on the magnetizing stand, using the proper jaws. Note the position of the pole end of the magnet marked "A" in the magnetizing stand, so that when the

magneto housing assembly is remagnetized, the magnet will again be remagnetized in the same direction.

Slip the magnet (42) over the shaft of the inductor rotor (2).

Assemble the Woodruff key (38), rotor gear (47), and bearing (108) with the sealed end of the bearing against the rotor gear, using the special tool, on the shaft of the inductor rotor. This is a floating bearing, and equalizing washers are not required.

Locate the bearing (5) in the magneto housing (1), with the sealed end of the bearing toward the inside of the magneto housing.

Slip the inductor rotor (2), with the magnet (42), through the tunnel of the magneto housing (1) and bearing (5).

Stand the magneto frame on the gear housing end and rest the rotor shaft on a suitable steel plate. The plate should be so arranged that the gear housing mounting studs are clear of the plate. Use a drift to force the bearing (5) on the rotor shaft.

Press the oil seal (7) in the ball-bearing thrust plate (3). *Important:* The bellmouthed side of the seal must be toward the inside of the magneto. Assemble the ball-bearing thrust plate (3) in the magneto housing (1), using screws (4). Tighten the screws gradually and evenly and stake the screw heads.

Locate the magnet (42) against the shoulder on the pole pieces P and P'. The pole end of the magnet, marked "A," must make contact with the upper pole shoe P.

Mounting Gear Housing Assembly to Magneto Housing.—Mount the gear housing assembly (49) to the magneto housing (1) and secure it with fastening nuts (21).

The distributor gear (30) must be properly meshed to the drive gear (47). The white dot on the distributor gear tooth is meshed between two red lines on two drive gear teeth. This position can be noted through the observation hole in the gear housing (49). Apply a little U.S. 508 grease, with the fingers, on the surface of the distributor gear teeth. The backlash between the gears should not exceed 0.008 in.

Distributor Rotor (29).—Replace the apron (44). Mount the distributor rotor (29) to the distributor gear (30) and fasten with a screw (45). Secure the apron (44) to the magneto housing, using screws (50).

Breaker Assembly (39).—Fish the primary lead (82) from the breaker assembly (39) through the hole in the gear housing assembly (49) and slots in the apron (44). Assemble the breaker assembly (39) to the gear housing (49), using the fastening screws (26).

Place a copper washer (32) over the distributor gear shaft. Mount the cam (35) with a Woodruff key (36) and copper washer (33) on the shaft of the distributor gear assembly (30).

Assemble the timing indicator (109). Before securing the cam with the stop nut (41), half fill reservoir in shaft of the distributor gear assembly with Fiske BS bearing oil and insert the restrictor plug (92), using the proper tool. Avoid air bubbles.

The timing indicator on the compensating cam must line up with the red mark on the inside of the gear housing assembly. This position will automatically result in the correct internal timing of the magneto (see Internal Timing, page 376).

Remagnetizing.—At this stage of the assembly, remagnetize the magneto on the magnetizing stand. *Important:* The magnet (42) has previously been remagnetized separately. *When assembled in the magneto housing, the*

same direction of polarity must be maintained, that is, the same end of the compass needle must point to the same end of the magnet when separately magnetized and when magnetized in the assembled condition.

Completing the Assembly.—Fasten the insulation plate (14) to the magneto housing with screws (62). Mount the coil (15), using fastening screws (19 and 54). Connect the primary cable assembly (82) from the breaker assembly (39) to the terminal block (103) on the side of the coil (15). Assemble the insulation plate (25) to the distributor block (24) and secure it to the magneto frame, using fastening screws (40). Check the air gap between the electrodes of the distributor rotor (29) and distributor block (24), with a gage. This air gap must not be greater than 0.050 in.

After the testing and performance test, the following parts should be assembled. Mount the dust cover assembly (16) and secure it with nuts (21). Fasten the breaker cover (34) to the gear housing (49) with nuts (21). Replace the radio shield assembly (23) and fasten it with the proper screws. Retest.

Assemble the spline coupling (12), washer (11), lock washer (8), castle nut (10), and cotter pin (9) to the drive end of the inductor rotor shaft.

Testing and Performance

Testing.—Disconnect the breaker lead from the block on the primary side of the coil. Connect one lead from a high-grade a.c. ammeter (0 to 3 amp. range) to the block (103), and ground the other lead on the magneto frame. If the magneto is properly magnetized and the electrical performance of the coil is satisfactory, a minimum reading of 1.75 amp. will be obtained at 400 r.p.m., magneto speed.

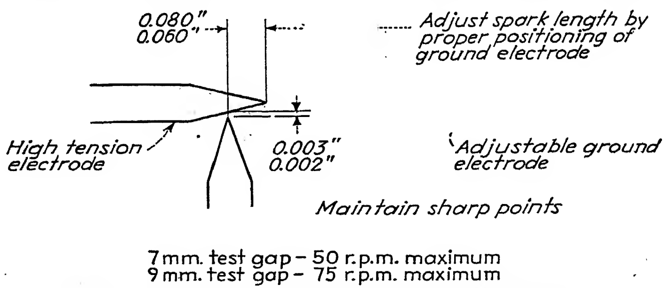


FIG. 12.—Test gaps for magnetos that have been remagnetized.

If this reading is lower than 1.75 amp., the magnetizing stand should be checked. If the voltage is proper, the magneto should be remagnetized, according to instructions.

The coil is checked on a Koilster coil tester. Replace the coil if the reading obtained is below 60 or above 100, as indicated on the coil test instrument. The coil should be tested cold.

If the coil tests within the prescribed range, the magneto has been remagnetized, and the current reading is still below 1.75 amp., then the charger used is of insufficient strength completely to saturate the Alnico magnet.

Performance.—After remagnetization, operate the magneto at 2,000 r.p.m., with 9-mm. pointed, three-electrode test gaps and short-circuit

magneto primary, 50 times in rapid succession to reduce magnetization to a stable value (see Fig. 12).

Operate the magneto for 15 min. at 2,000 r.p.m. magneto speed, firing 10 mm. pointed, three-electrode test gaps. The magneto must be capable of firing these gaps without missing between 200 and 3,000 magneto r.p.m. If tested in connection with the complete radio-shielded ignition harness, the test gaps should be reduced to 9 mm. for 100 per cent firing between 400 and 3,000 magneto r.p.m.

Booster Current.—Run the magneto at 500 r.p.m. with the grounding terminal grounded and the high-tension booster cable connected to the booster terminal in the magneto distributor block. Use 7-mm. pointed, three-electrode test gaps for checking the spark output of the booster through the magneto distributor. The booster spark follows the magneto spark, which should be checked by disconnecting the grounding terminal intermittently.

Low-speed Limits.—The low-speed limits, or coming-in speeds, should be checked on properly adjusted test gaps (see Fig. 12).

Periodic Inspection and Maintenance

Lubrication.—No lubrication is required between major overhaul periods.

Breaker Assembly.—*Important:* Periodically, check the instant at which the contact points start to open on cam lobe 1, with the position of the timing indicator in relation to the red timing mark on the gear housing. This is done by removing the breaker cover from the gear housing. Withdraw the nut, using the proper tool. Remove the condenser, primary cable lead, and breaker grounding spring. Connect one lead of the electrical timing indicator to the fastening bolt and the other lead to the ground.

Turn the engine in a counterclockwise direction until the timing indicator lines up with the red mark on the gear housing. At this position, the contact points should start to open, as indicated by the signal lamp of the electrical timing indicator going out.

If the contact points do not open at this position, loosen the adjustable contact bracket locking screw and shift the adjustable contact bracket by means of the eccentric screw until the signal lamp of the electrical timing indicator starts to go out. Tighten the screw and recheck the contact adjustment.

Recheck the synchronization of both magnetos to the engine timing marks (see Timing and Installation, page 376).

Reassemble the breaker assembly.

EISEMANN MAGNETO

Many light planes use the Eisemann magneto, either singly or in pairs. Where only one magneto is used the unit has a standard inductor rotor shaft and rotates counterclockwise. Where dual mounting is used, the AM-4 horizontal flange magneto has an inductor ½ in. longer than standard. The rotor shaft is extended to take the magneto drive gear supplied by the engine builder. With dual magnetos, both turn clockwise.

The impulse starter furnished with all such magnetos has a lag of 25 deg. with the lugs positioned at spark at 30 deg. before horizontal.

A recent change in these magnetos has replaced the carbon brush distributor with jump spark distributor plates. Sectional views of the AM-4 magneto, with the carbon brushes, are seen in Fig. 13. In Fig. 14 are shown the gears driving the distributor while Fig. 15 shows the distributor in place.

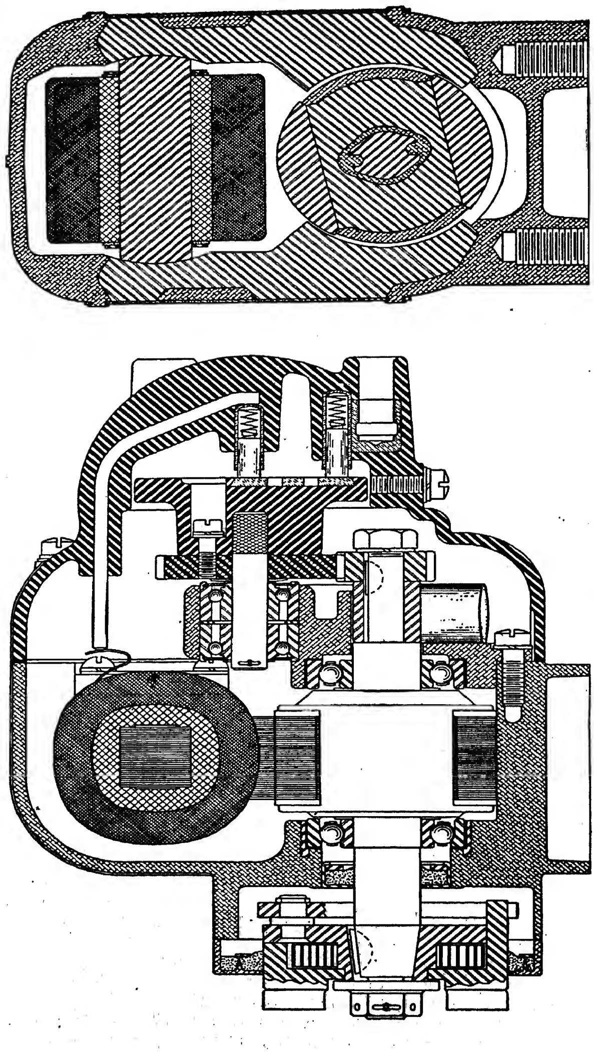


Fig. 13.—Sectional view of Eisemann AM-4 horizontal flange magneto with ball bearing distributor.

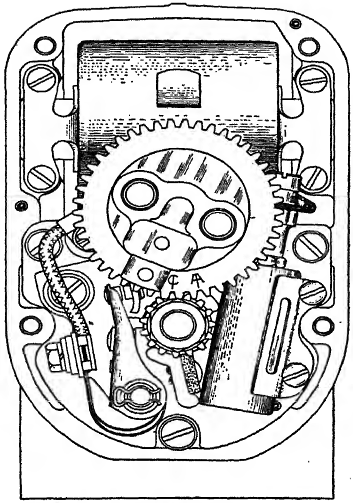


FIG. 14.—The gears that drive the distributor.

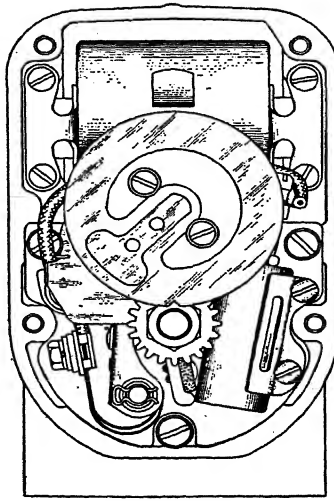


FIG. 15.—The distributor in place on the larger gear.

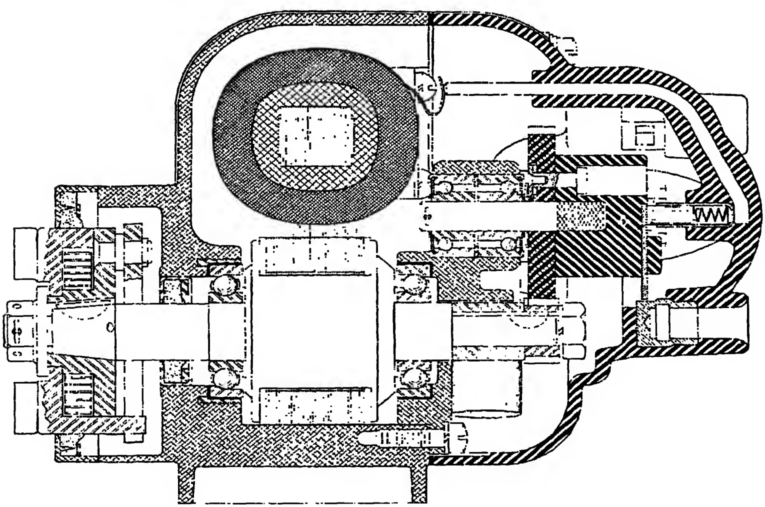


FIG. 16.—Newer type Eisemann jump-spark magneto.

Figure 13 shows the two carbon contact brushes, one being in the center, while the intermittent contact is below it.

Figure 16 shows a late model jump spark Eisemann magneto with only one contact, the center carbon. The revolving spark arm is at the top delivering a spark to the upper lead shown.

Characteristics of Models of Eisemann AM-Magnetos

Two models of Eisemann magnetos are especially adapted for use on airplane engines. They are available for use on four- and six-cylinder engines.

AM-4.—Two-lobe cam and two-pawl impulse starter. Carbon brush distribution now changed to jump spark. Crankshaft speed on four-cycle, four-cylinder engines.

AM-6.—Two-lobe cam and two-pawl impulse starter. Jump spark distribution. Driven at 1½ times crankshaft speed on four-cycle six-cylinder engines.

Care of AM Models

Timing Magneto.—All AM models are fixed spark and should be timed to the engine with the flywheel in the firing position recommended by the engine manufacturer.

These magnetos should be timed to each engine as directed by the maker of the engines on which they are used. Directions are given in the sections describing these engines.

Flange-mounting Magnetos.—Before mounting the magneto on the engine, rotate the flywheel to the firing mark on compression stroke in cylinder 1. Then turn the magneto rotor by hand in the reverse of operating direction (to avoid impulse starter engagement) until the metal insert in the distributor disk is at cable 1 position. Engage the impulse starter lugs in the slot with the magneto slightly off vertical, if necessary.

Base-mounting Magnetos.—Insert a piece of cigarette paper or cellophane between the contact points to determine accurately when interruption takes place and spark occurs. Afterward, make sure that no torn pieces of paper remain between the contact points.

Cleaning.—Use a clean soft cloth, dampened with gasoline, to remove carbon track from the face of the distributor rotor as well as any carbon dust that may be deposited on the inner surface of the distributor plate. After cleaning with gasoline, permit these parts to become dry before operating the magneto.

Do not remove the lubricant from the breaker cam.

Avoid the use of emery cloth, sandpaper, or any other abrasive material in cleaning the distributor plate, distributor rotor or breaker cam.

The use of a steel file on contact points is not recommended, but carborundum stone may be used to clean their surfaces, if necessary, after long periods of idleness.

Cables.—Replace cracked or chafed high-tension cables promptly.

All AM distributor plates are designed to accommodate a special clip, and no other clip is usable with these models.

It is important to press firmly when inserting cables, to make sure the cable clips bottom in holders and make contact with the brass insert as shown.

Contact Points.—Check the contact point opening after 1,000 hr. of operation, using a 0.020 in. feeler gage.

The gap between contacts, at full separation, should be within 0.019 to 0.021-in. limits.

Rotate the flywheel slowly in the reverse of normal operating direction (to avoid impulse starter engagement) until the breaker lever fiber rests on the summit of a breaker cam, and then insert 0.020-in. gage.

If the gap between in contact points requires adjustment, loosen (but do not remove) the breaker plate fastening screw and move the entire breaker assembly in either direction—toward the cam to increase the gap, or away from it to decrease the gap. Re-check the gap after tightening the breaker fastening screw.

Do not disturb the hex nut holding the breaker tension springs.

Lubrication.—The 15-mm. open-type ball bearings at each end of the magnet rotor and two 8-mm. closed-type ball bearings on the distributor shaft are grease packed.

The factory application should last for at least 2 yr. under average conditions. When the magneto is taken to an authorized service station for adjustment or repairs, the ball bearings will be repacked, if necessary, with the same high-melting acid-free grease.

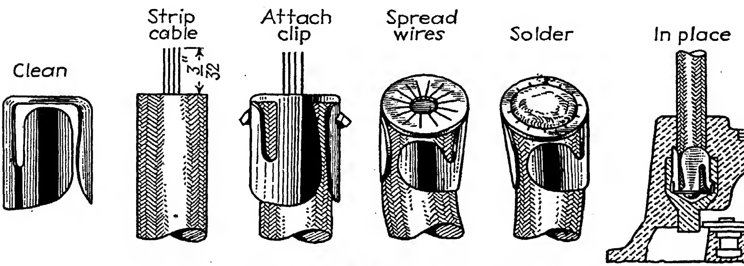


Fig. 17.—A method of soldering spring clips to cable ends to ensure good contacts.

The porous bronze, oil-retaining, distributor shaft bearing requires no additional lubrication. Apply *one drop* of medium grade crankcase oil to the breaker cam wick after each 500 hr. of use.

The impulse starters on the base-mounting magnetos may be lubricated by removing the dust cover.

Spark Plugs.—Periodic inspection of the spark plugs is recommended, after each 250 hr. of operation, or at more frequent intervals. Keep them clean and in correct adjustment (0.025 in.). Fouled spark plugs, or gaps in excess of 0.025 in., impose a severe strain on the magneto and may cause hard starting of the engine or failure of the magneto.

Ignition Cable Connections.—It is important that a good contact be secured between the magneto and the ignition wire leads. Spring clips should be soldered to the ends of the cable wires. Be sure the metal of the clip is clean as shown in Fig. 17. Strip the end of the cable clear of insulation for about $\frac{3}{32}$ in. Push the bare wires through the hole in the clip, as shown. Spread the wires out across the end of the clip, and then solder the wires to the end of the clip. Then, when the end of the cable is pushed into the magneto terminal, as shown at the right, there will be no question as to having a good contact.

Cables must be connected to spark plugs in accordance with the firing order of the engine. Replace a cracked or chafed cable without delay. Cut to the correct length and install cable clip 21461.

Use 7 mm. high-tension cable of the best grade obtainable for replacement purposes.

Adjusting Contact Points.—Check the contact point opening after each 500 hr. of operation, and adjust the gap if necessary.

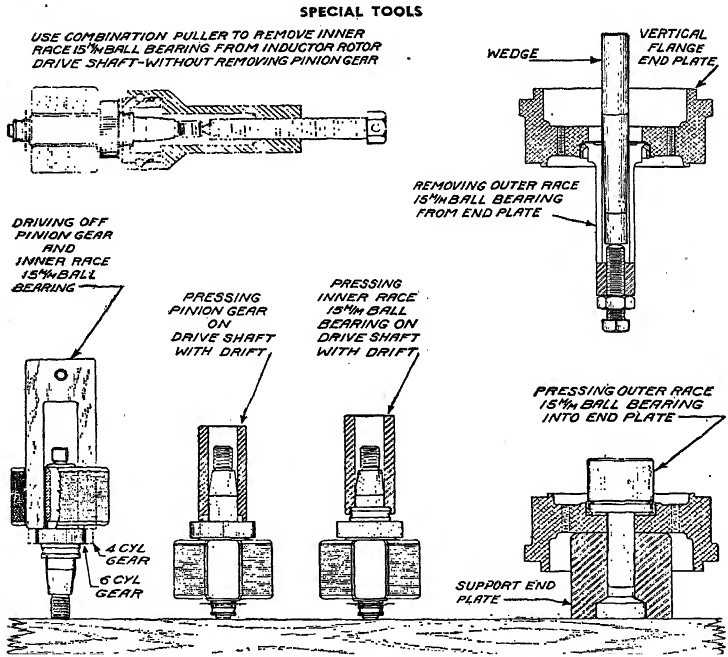


Fig. 18.—Tools for removing and replacing gears and bearings on Eisemann magneto.

Do not use a steel file on the contact points. If they wear unevenly or become pitted, a fine carborundum stone may be used; afterward remove all dust particles with a clean, dry cloth.

Insert a 0.020-in. leaf gage between the contact points after positioning the breaker lever bumper block on the summit of the cam lobe, that is, when the contact points are fully separated. If necessary to adjust the gap, loosen the brake plate holding screw slightly—but not enough to lose all friction of the lock washer. Now, insert a screw driver in the space between the head of screw and lip on the bracket, or in the space between the head of screw and lip on the bracket, moving the bracket one way or the other, as may be necessary, to obtain a 0.020-in. gap. Then tighten screw.

Turn off the switch when cranking the engine to position the cam for full separation of contact points.

Base-mounting Magnetos.—Back off the sleeve cover held by springs attached to the impulse starter catch plate. Release the pawls by hand

SPECIAL TOOLS

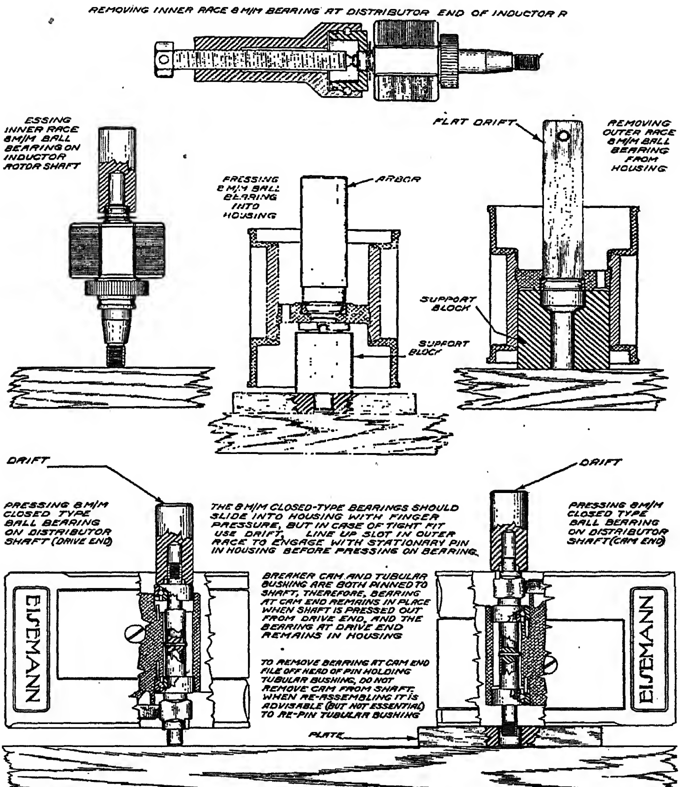


FIG. 19.—Special Eisemann tools for removing and replacing ball bearings.

when they engage on the catch plate, simply by depressing the short end of the pawl, as shown.

Flange-mounting Magnetos.—Lift the crank slowly. Stop cranking when the impulse starter releases. If the breaker lever bumper block does not come to rest on top of the cam, it will be necessary to rotate the flywheel in the reverse direction.

Breaker Points.—The life of contact points can be prolonged by maintaining the correct adjustment (0.020 in.). But, in time, it will become necessary to renew them. When new contact points are required, the entire magneto should be given a thorough examination and test at a service station.

Make emergency field replacements as follows:

Complete Breaker.—To replace the complete assembly, remove slotted nut from the condenser binding post; lift the lead from the breaker to condenser, and remove two breaker plate fastening screws. Do not loosen screws.

A spark of maximum intensity is delivered when contact point interruption coincides with a break or "edge distance" of 0.078 to 0.118 in. between the edge of the inductor rotor and the edge of the stationary pole shoes.

Normally, the wear on contact points is offset by wear on the breaker lever bumper block, and compensating wear keeps "edge distance" within the 0.078 to 0.118 in. limits.

The operating rotation of the magneto, viewed from the drive end, is indicated by the arrow on the impulse starter.

Distributor Plate.—The system of ventilation provided should prevent condensation inside the housing and corrosion of metal parts, under all ordinary atmospheric conditions. But when the weather is very humid, it may be found advisable and necessary—particularly after long periods of idleness—to wipe the inside of the distributor plate with a clean, dry cloth, to remove any moisture that may be present.

Ventilator.—It is not recommended that the ventilator assembly be taken apart, but if this is done, reassemble it in correct order.

Gasket.—Examine the gasket whenever the distributor plate is removed. Install a new gasket if the original cracks or becomes wrinkled.

Distributor Rotor.—This part is supplied only as a complete unit.

Breaker Cam.—These two parts are sold as a single unit. Do not touch the cam surfaces with a file, emery cloth, sandpaper, or any other abrasive material. If the cam becomes scored, it must be replaced.

Distributor Gear.—This part is supplied only as a complete unit.

Special tools are provided for the disassembling and the reassembling of the magneto. Some of these tools and instructions for use are shown in Figs. 18 and 19.

SECTION XII

SPARK PLUGS

SERVICING B G SPARK PLUGS

Aviation requires that equipment be maintained to the highest standards at all times. Since proper functioning of the engine and the safety of the aircraft depend in a large measure on the condition of the spark plugs, it is important that they be properly handled. Careful inspection and correct servicing pay. The following suggestions have been prepared from long experience in spark-plug maintenance.

Tools.—Proper tools are essential for successful service work. Many plugs are damaged by ill-fitting wrenches and by mishandling in service. Special tool kits have been developed for servicing B G and other spark plugs. When the amount of spark-plug reconditioning warrants, a special reconditioning bench is recommended.

The reconditioning bench, shown in Fig. 1, was planned to have all necessary equipment fixed in place, to have the necessary replacement parts in convenient bins, and to provide a locked tool compartment.

The left compartment houses the magneto and auxiliary spark gaps. It is also provided with shelves. The center compartment has four shelves of slat construction; being heated by one or more 100-watt electric-light bulbs, it is used for storage to keep plugs free of moisture. The right compartment provides additional storage space. Small bins above the bench are used for holding miscellaneous parts. The locked tool compartment is on the right.

The top of the bench is clear of all unnecessary obstructions. The electric motor for driving the magneto is arranged so that the shaft will accommodate collets used for convenience in cleaning spark-plug cores. The small tube leading from the test bomb to the pressure line is concealed except where it passes through the bench for attachment to the test bomb fitting. Should a larger bench be desired, the addition of another compartment will provide approximately 2 ft. more of working space. A set of supporting legs should be placed under the middle of the bench, if the compartment is added.

Inspection.—*Prolonged spark-plug life is obtained, much unnecessary work eliminated, and possible damage to the plug avoided by intelligent servicing.*

Spark plugs should be inspected each time they are removed from an engine. *It is not however, always necessary or desirable to disassemble a plug completely* for inspection purposes. If the plug has not been functioning properly, the electrode clearance (page 401) should be checked and, if necessary, reset to proper clearance. A degreasing process is most effective in removing oil and dirt from plugs without disassembly, although a moderate accumulation of oil may be readily removed with clean, unleaded gasoline. Do not allow it to remain in the gasoline too long. The blackened appearance of the end of the plug in the absence of heavy oil and lead deposits is not detrimental to its operation.

A bomb test (page 405) should follow inspection, adjustment of electrode clearances, and general cleaning.

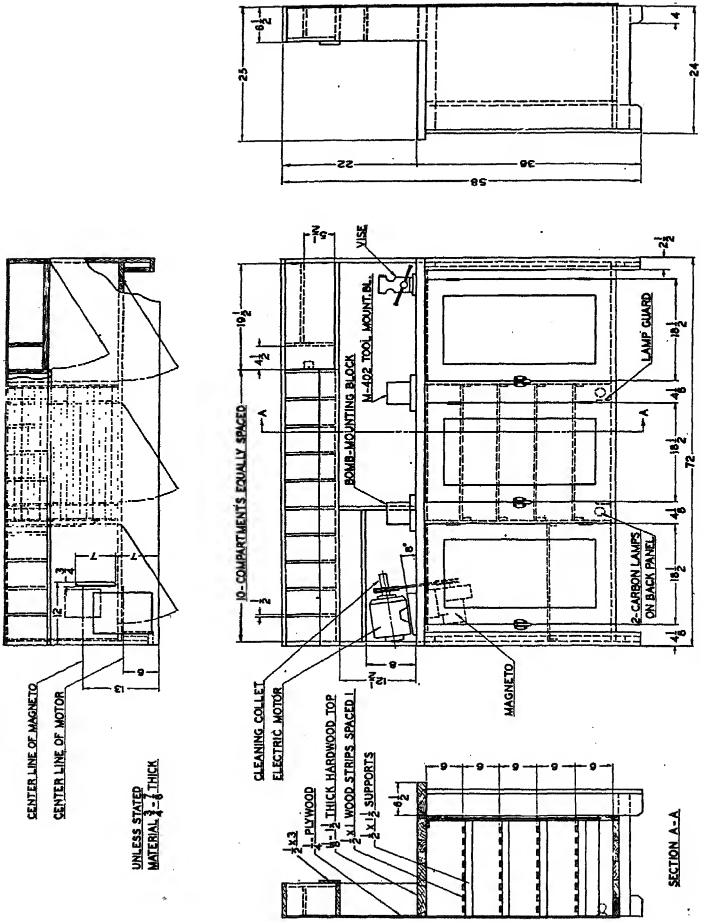


Fig. 1.—Bench recommended for reconditioning and testing plugs.

Cleaning.—A simple cleaning tank for removing oil and grease is a metal container approximately 8 in. in diameter and 12 or 14 in. high. A coil comprising several turns of ⅜-in. copper tubing should be wound to fit snugly inside the container extending downward from the top approximately

4 in. Both ends of the coil are brought out of the top of the tank to permit the attachment of rubber hose as in Fig. 2. Cold water is circulated through the coil during the degreasing operation. This cooling coil condenses vapor from the boiling solution, returning it to liquid form. Put the plugs in a wire basket, small enough in diameter to pass through the copper il

The cleaning solution used is trichloroethylene, sold under the trade names of Triad and Blacosolv. *Do not use gasoline in this method.* The liquid, which is heated to the boiling point, should not extend up to the cooling coil. A small electric stove provides a convenient means of heating.

Complete plugs, cores, or shells are placed in the basket and immersed in the boiling solution for about 5 min. The basket is then slowly raised to the top level of the tank where the parts are submitted to the vapor of the boiling solution for a minute or two, then removed and permitted to dry.

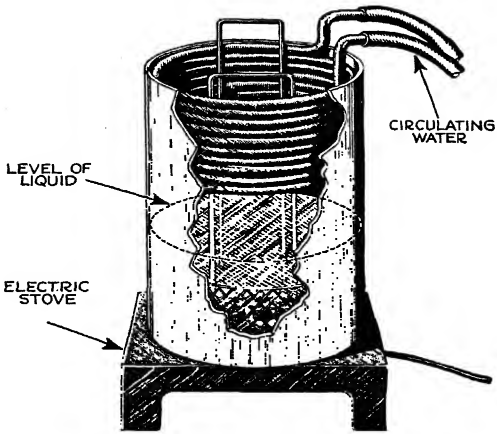


Fig. 2.—Cleaning tank for removing oil.

This operation is recommended when cores and shells are disassembled, prior to starting the general reconditioning procedure. However, this process will remove only oil and grease; it does not remove carbon deposits or solid matter. The solution should be changed when dirty.

Care should be exercised not to inhale the fumes.

Disassembly.—B G spark plugs are constructed in two pieces: the core and a shell. These may be readily taken apart for inspection and cleaning (see Fig. 3).

A vise socket holds the spark plug in position for assembly. This eliminates the danger of squeezing the core nut too tightly, which frequently occurs when plugs are held directly in the vise jaws.

To remove the core assembly from the shell, insert the plug in a proper socket held in a vise as illustrated in Fig. 4. For plugs having a $\frac{9}{16}$-in. hexagonal coupling nut, use *A*-203 vise socket; for those having a $\frac{7}{8}$-in. hexagonal coupling nut, use *A*-204 split, hinged vise socket.

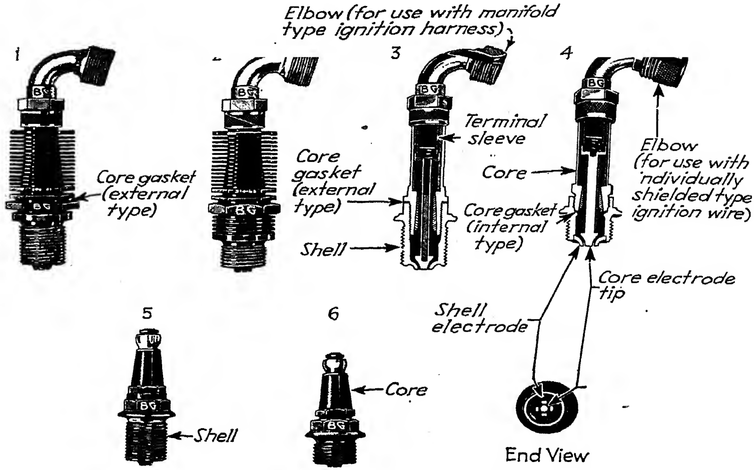


FIG. 3.—Construction of B G spark plugs.

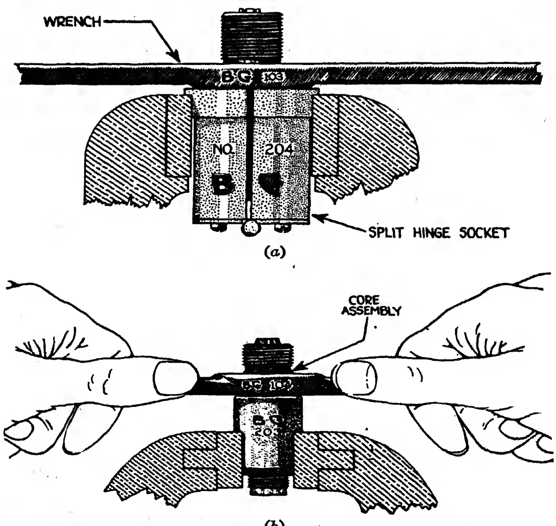


FIG. 4.—Holders for servicing spark plugs. (*a*) Hinged vise socket for plugs with 7/8-in. core hex. (*b*) Vise socket for plugs with 9/16-in. core hex.

Do not hold the plug in the jaws of the vise as excessive pressure may damage the internal insulation of the plug.

Loosen the core from the shell with the proper wrench.

Never use an open-end wrench for disassembly. A slip may result in a bent center electrode and a ruined core.

Remove the core gasket. To remove the internal copper core gaskets use a gasket removing tool, as in Fig. 5. Insert the tool in the end of the shell and push the gasket out. Some types of plugs have gaskets placed externally between the core and shell. These are removed when the parts are separated.

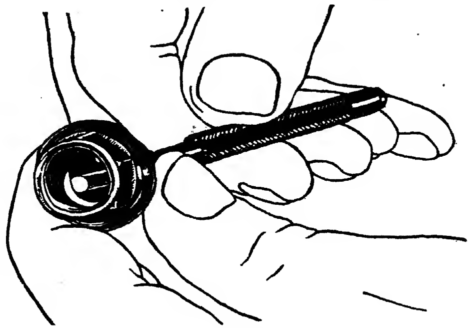


Fig. 5.—Removing internal core gasket.

Place the cores and shells in the bench work tray as shown in Fig. 6. Careless handling of spark plugs causes burred or damaged threads and other damage. Trays protect both shells and cores and provide an orderly means of handling them during servicing operations. Details of the trays are given in Fig. 7.

Core Cleaning.—The correct method of cleaning cores is illustrated in Fig. 8. Special collets are used to hold the cores while they are being cleaned. They are designed to be fastened to the shaft of a $\frac{1}{4}$-hp. 1,750-r.p.m. motor on a tilted mounting base. The collet holds the core in place without tightening due to the speed of the motor and the fact that the base is tilted. Collet *A*-10 takes all unfinned shielded plugs. With its

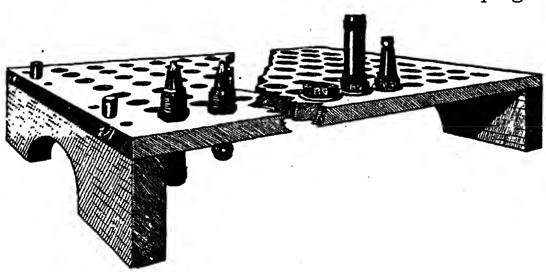


Fig. 6.—Tray for holding plugs on workbench.

bushing or adapter in place it is also used for holding unshielded plugs. Collet *A*-11 accommodates finned plugs only.

Cores may also be cleaned by holding them in a lathe or drill-press chuck. If this method is employed, avoid excessive tightening of the chuck.

Use No. 150 Aloxite cloth strips or 00 sandpaper to remove all traces of carbon, lead oxybromide, etc., from exposed mica. Polish with No. 300 Aloxite cloth or 0000 crocus cloth. Mica must be smooth when finished.

Never use emery, carborundum, metal buffing wheels, or sandblast for cleaning mica plugs. Particles of such materials may become imbedded in the mica insulation and cause ultimate and premature failure of the spark-plug core.

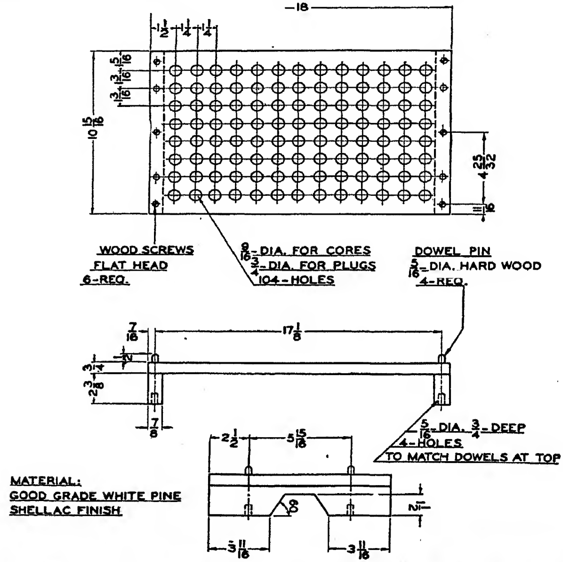


Fig. 7.—Details of bench work tray.

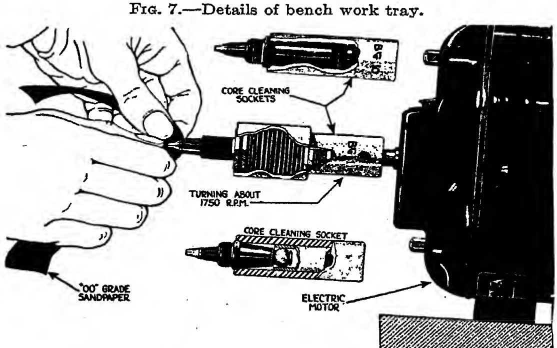


Fig. 8.—Cleaning cores with 00 grade sandpaper.

Remove as little of the exposed mica insulation as possible during the cleaning process. Do not reduce the diameter of the electrode tip next to the mica more than necessary.

Cleaning and Shaping Core Electrode.—Irregularities caused by burning of the electrode tips should be removed by shaping them to a true cylindrical contour, in order to set the gaps accurately when the cores are assembled in the shells. The use of 150 Aloxite cloth or 00 sandpaper fixed to a ⅜-in. round wooden stick will save time in removing traces of pits and scale from the curved portion of the center electrode tip.

Washing and Drying Core.—Degrease, or wash the cores, using a brush and clean unleaded gasoline. When cleaning the inside of the barrel of shielded plugs by hand, take care not to damage the mica insulation. A small rounded wooden stick with a layer of soft cloth dipped in clean unleaded gasoline, or carbon tetrachloride, serves the purpose. After inserting the cloth-covered stick, turn it in the direction in which the mica is wrapped.

Plugs should never be permitted to stand in gasoline for more than a few minutes as there is a tendency for the gasoline to carry particles of carbon and dirt between the layers of the insulation. Place the clean cores in the bench work tray (Fig. 6), electrode end up, to dry.

Rust Prevention.—The core threads should be clean and dry. Coat them with light oil or a suitable rust inhibitor. An excellent rustproofing oil is

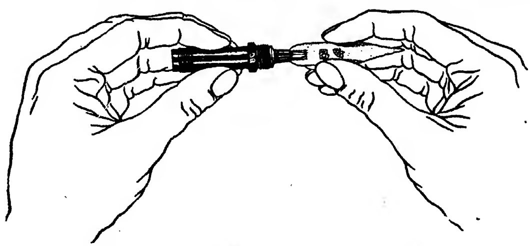


Fig. 9.—Checking diameter of electrode tip.

No-Ox-ID, manufactured by the Dearborn Chemical Company, Chicago, Ill.; grade A will be found to be the proper consistency.

Core Inspection.—After wiping the core with a clean cloth, inspect for breaks or injuries to the insulation. If the insulation is broken, flaked, or dented, or if there are holes in the mica, the core should not be used. Likewise, if any of the mica laminations or washers on the electrode end of the core project beyond the adjacent laminations, the core should be discarded. Note the condition of the terminal connection, electrode, and threads.

Damaged threads should be corrected by chasing with the proper die or dressed with a toolmaker's file or a half-round file which has been ground smooth on the curved surface. Remove only the burrs. If too much stock is removed the plug will be loose.

Shoulder Diameter Electrode.—Measure the diameter of the center electrode shoulder at the point where the mica laminations start. Use a gage as illustrated in Fig. 9. If the shoulder passes through the opening in the gage, it should be discarded. Gages may be obtained from B G upon request, at no charge.

If this measurement is taken with a micrometer, the core should be discarded when the diameter has been reduced to less than 0.260 in.

Tip Diameter of Core Electrode.—Satisfactory gap adjustments cannot be made when the end of the center electrode tip is less than 0.090 in. in

diameter. When this occurs, new tips can be welded on at a moderate charge, if the cores are returned to the factory.

Cleaning the Shell.—Where large quantities of shells are being serviced and facilities are available, removal of carbon and lead deposit is best accomplished by placing the shells in a heated salt bath. Either of two types of salt baths may be used: Heatbath-Penetrate No. 1 (a trade-marked product of the Heatbath Corp., Springfield, Mass.) or a mixture of equal parts of commercial sodium nitrate and potassium nitrate. The latter may be obtained from any chemical supply house. The first method will clean the shells thoroughly in 5 to 10 min. after the bath has been brought up to working temperature. The second method requires about 30 min.

Cleaning by the two methods uses the same procedure. Conduct the operation where no fire hazard exists. Owing to smoke and fumes from burning oil and carbon, provisions should be made to ventilate the area over the pot. Do not heat these materials over a coal or charcoal forge. Use a container that will not leak. A cast-iron or steel pot 5 or 6 in. in diameter and of about the same depth should be used. The electric pot illustrated in Fig. 10 is made by the H. E. Trent Co., Philadelphia. With this pot about 1 hr. is required to bring the material up to working temperature when the switch is set to "high." If a large number of shells are to be cleaned without interruption, the switch can be left in this position. If the cleaning progresses intermittently, the switch may be turned to "medium" or "low."

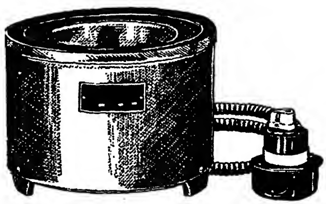


FIG. 10.—Electric heating pot for cleaning shells.

Fill the pot about two-thirds with cleaning material.

Heat the material to 950°F.

Place the shells in a wire-mesh basket or perforated metal container which will fit into the pot.

With a long handle, lower the basket containing the shells into the heated salt bath. It is important that the basket and shells be absolutely dry. The slightest trace of moisture will be instantly changed to steam on contact with the hot bath. If this occurs, the molten solution will spatter and be thrown out with the possibility of seriously burning the operator. *Goggles, leather gauntlet gloves, and long sleeves should be worn. The sleeves should be pulled down over the gauntlets so that nothing will fall inside if spattering occurs.* When very dirty shells are placed in the salt bath, the oil and dirt will ignite. The flame soon burns out.

Leave the shells in the salt bath until bubbling stops. This indicates that the cleaning has been completed. Lead and carbon will deposit in the bottom of the pot. It should be frequently removed by means of a ladle.

Remove the basket of shells and allow them to drain.

After they have cooled for 10 to 15 min., dip them in hot water to remove the remaining salt. As the shells are at a high temperature when removed from the bath, steam will be generated and water spattered if they are immersed too soon. To eliminate danger to the operator, the receptacle holding the water should be provided with a shield.

The shells should be thoroughly rinsed in running water to remove all traces of salt.

Cleaning Shells in Small Quantities.—When the quantities of shells do not justify the cleaning methods previously outlined, they may be soaked in clean, unleaded gasoline to remove the oil and soft carbon. Hard carbon and lead deposits may be removed with a knife or round wire brush. A small wad of steel wool wound on a drill and used in a lathe or drill-press chuck is effective in cleaning the inside of the shell. Care should be used to prevent damage to the internal threads or core gasket seat.

Rust Removal and Prevention.—The foregoing methods of cleaning will not remove rust. Rust can be removed by "pickling" in a 10 per cent

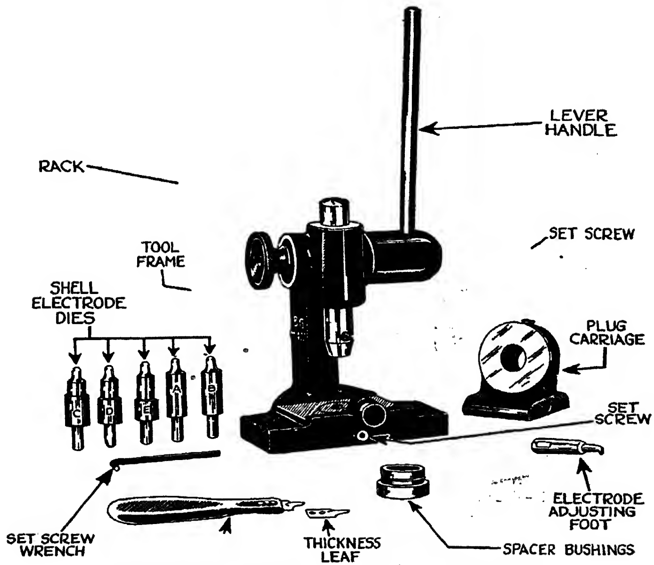


Fig. 11.—Tool for forming and adjusting electrode.

solution of commercial sulphuric acid at 120°F. for a few minutes. The shells should not be left in the pickle after the rust has been removed as the acid will attack the metal. After removal, they should be rinsed thoroughly in running water and coated with light oil or a suitable rust inhibitor.

Drying.—The shells should be prepared for drying by placing them in a metal basket and dipping them in boiling water. The basket should then be swung in the air or blown off with a fan or compressed air to remove any remaining water.

Bluing.—A desirable blue finish may be given to the surface of the shells after thoroughly cleaning *and drying*. Dip them in a fresh hot salt bath solution, similar to that used for cleaning, for 10 to 15 min. After draining, any remaining salt should be removed by dipping in hot water and rinsing thoroughly in running hot water.

Inspection.—All shells should be inspected for damaged hexagons, condition of the electrodes, and burred threads, and any damage should be repaired.

When the shell electrodes have been burned away to 0.032 in., they are too thin at the tips and can no longer be properly adjusted. They should be discarded and new shells used.

Electrodes.—The four-point shell electrode is designed to conform to the special shape of the center electrode tip throughout its length. With proper clearance between the surfaces of the shell and core electrodes, less frequent gap setting is required and longer electrode life is obtained. *In order that the spark-plug shell electrode may conform to the curvature of the core electrode and have uniform clearance throughout its length, it must be correctly formed with a specially designed tool.*

The forming and adjusting tool (Fig. 11) makes it possible to form and adjust electrodes with factory precision.

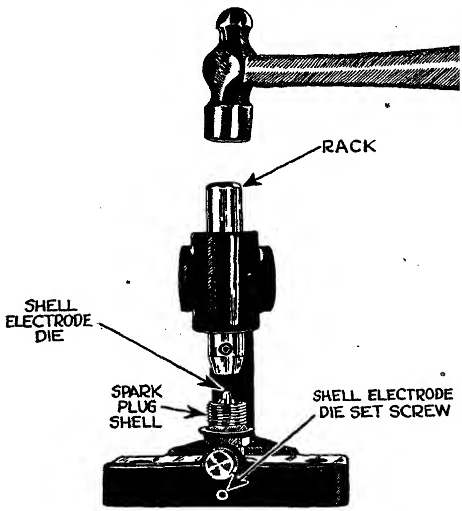


Fig. 12.—Forming shell electrodes.

Electrode Forming.—The tool should be mounted on a solid base at a suitable working height. The electrode adjusting foot should be removed from the rack, and the rack setscrew tightened to clear the rack guide. The special thumb screw and washer at the end of the shaft opposite the lever handle should be removed and the lever handle with pinion shaft withdrawn. Select the proper male die and tighten it in the base with a setscrew.

Five specially shaped removable male dies are provided to cover the range of B G spark-plug shells. The female die is recessed in the lower end of the rack.

Die No.	For B G Spark-plug shells
A	298-GS, 314-GS, 316-C
B	320-S, 321-S, 321, 323, 344, 349, 375
C	3B2-S, 3B2
D	4B2-S, 4B2
E	5B2-S, 5B2

The interior of the shell must be free from carbon and lead deposits and the assembly gasket removed before the reforming operation is attempted. This is important, otherwise the shell will not fit properly over the forming die.

Place the shell over the male die, as shown in Fig. 12.

Lower the rack so that the female die fits firmly over the shell electrode.

Use a 1-lb. lead or copper hammer and strike a sharp blow at the upper end of the rack; the hammer should be held about 6 in. above the rack. Excessive force should not be used. If the electrode does not closely conform to the shape of the die, a second blow should complete the operation. It is important that the electrode be formed to a perfect fit on the die.

Raise the rack and remove the shell.

Thread Lubrication.—Before assembly, the core threads should be treated with B G mica thread lubricant, a special preparation to prevent cores from seizing in the shells when the plugs are subjected to the heat of an engine. It contains the proper proportion of finely screened mica powder and a special grade of oil. A thin coating should be wiped evenly on the core threads. It should be applied carefully so as not to get it on the mica insulation. If an excessive amount is used, it will flow onto the lower mica insulation and may result in the plug's misfiring when it becomes warm.

Gaskets—Core.—With the cores arranged in a bench work tray, electrode end up, place a core gasket on each. *Core gaskets should never be used a second time.* The use of a new gasket is necessary to maintain a gas-tight joint between the core and shell. Core gaskets should not be used if they are scored, burred, or distorted. It is difficult to obtain satisfactory electrode clearance the full length of the electrode when too thin gaskets are used.

Spark-plug Assembly.—This operation is similar to that employed for disassembly. Use the correct socket held in a vise. Screw the core into the shell with the fingers; place it in the vise socket and tighten it with the proper wrench (see Fig. 4).

Too much pressure applied to plugs with the internal type of assembly gaskets will cause distortion of the gasket, force it into the mica washers below the seat, and damage the insulation. The pressure exerted should not exceed 350 in.-lb. (approximately 30 ft.-lb.). Moderate tightening is sufficient to secure a good gas-tight joint.

Electrode Clearance.—The standard electrode clearance for B G spark plugs supplied to meet the specifications of government services and engine manufacturers is 0.015 in. unless otherwise specified. Satisfactory performance may be secured when operating conditions permit, with electrode clearances set at 0.012 in. for use in engines of high specific power output, particularly those having shielded ignition systems. Small gaps may result in slightly poorer idling characteristics. Plugs used in shielded ignition systems should not be operated with electrode clearances in excess of 0.020 to 0.022 in., plugs in unshielded systems 0.025 to 0.028 in. Irregular or rough operation results when the clearances are too great. The recommendations of engine manufacturers should be followed in making electrode adjustments.

Electrode Clearance Adjustment.—The electrode forming and adjusting tool is used for adjusting B G spark electrode clearances. It may be operated with either right or left hand. As illustrated in Fig. 11, it is set up for right-hand operation. For left-hand operation, it is necessary only to reverse the position of the electrode adjusting foot, plug carriage, and lever handle assembly.

The tool should be assembled for use by replacing the lever handle and pinion shaft. Insert the electrode adjusting foot in the rack and secure it firmly by means of the rack setscrew and hexagon setscrew wrench. Remove the male forming die and place the plug carriage on the base.

Screw the spark plug firmly into the carriage. Use the spacer bushing, inserted in the carriage, for long-reach plugs. The early model of this tool

employs two bushings: one for short-reach and one for long-reach plugs. Bushings are retained in place by wire lock rings and can be inserted or removed without tools.

Use the lever handle to raise and lower the rack to see that the electrode adjusting foot just clears the end of the spark-plug shells. Tighten the plug carriage lock screw. This applies to all B G spark plugs not having electrodes recessed in the shell.

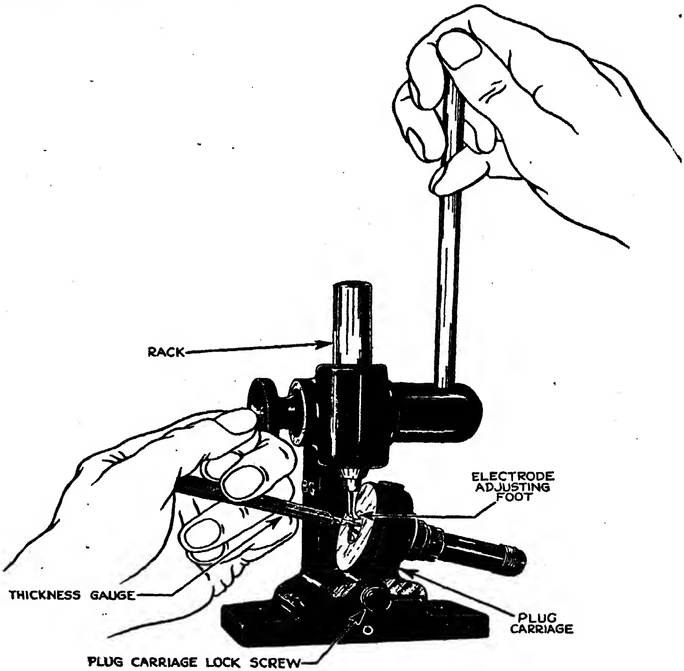


Fig. 13.—Adjusting shell electrodes.

For plugs having electrodes recessed in the shell, the plugs are screwed into the carriage as described, but the carriage is moved slightly farther until the electrode adjusting foot extends into the recess in the end of the shell. The carriage is locked finger-tight in this position. The rack can be raised only a short distance but the plugs may be inserted and removed without difficulty.

Turn the knurled face plate until one electrode point is directly under the electrode adjusting foot. Be sure the foot sits squarely on the electrode.

Insert a thickness gage of desired size between the center and shell electrode, as illustrated in Fig. 13. Use the lever handle to exert pressure on the shell electrode, depressing it until a snug fit exists between the thickness gage and center electrode. Adjust the remaining shell electrode points in a

similar manner. Prevent "overbending" by not applying too much pressure on the lever handle.

Remove the plug from the carriage and check the electrode clearance with a B G wire feeler gage. Use type A-503 for 0.015-in. gaps and type A-550 for 0.012-in. gaps.

Test Equipment.—A typical test equipment is illustrated in Fig. 14. The valve-type bomb shown is intended for operation with a carbon dioxide or nitrogen gas storage cylinder or compressed air tank. A hand-pump-type test bomb may be substituted where it is not convenient to use carbon dioxide, nitrogen, or compressed air. This latter type bomb incorporates a small

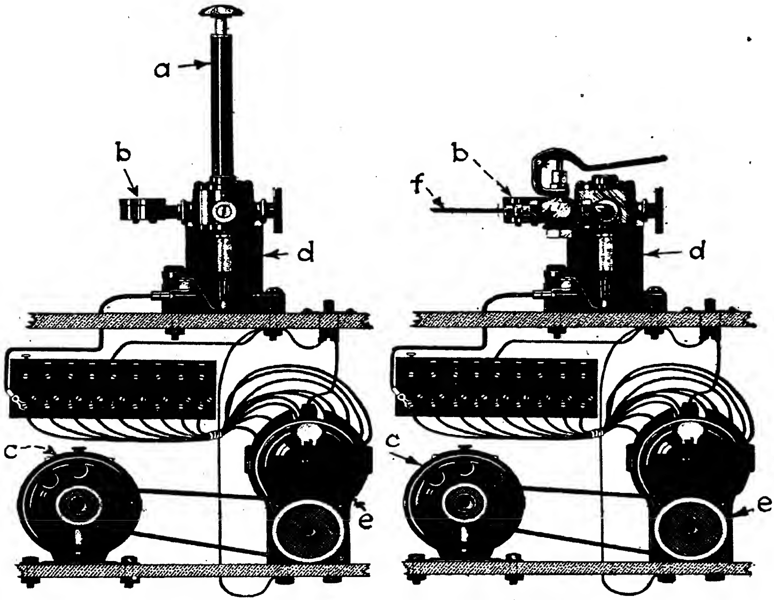


Fig. 14.—Equipment for testing spark plugs.

plunger pump. A few strokes of the pump will supply the desired test pressure. Either the M-397 valve-type test bomb or the M-398 hand pump type test bomb (see Fig. 15) may be obtained from B G dealers. Use copper tubing ⅛ in. O.D. 0.035-in. wall (No. 20 Stubbs gage) and compression fittings for the pressure line between the test bomb and pressure tank.

A standard service type magneto is desirable for test work, particularly where tests are made at the higher bomb pressures. For use with test pressures of 150 lb. per sq. in. or higher, consistent results can be obtained only by using magnetos with the latest type coils and magnets.

The speed of the magneto should be arranged to provide approximately 1,000 sparks per minute to the plug under test.

A motor of $\frac{1}{4}$ hp. is suitable for driving the magneto.

The importance of using a magneto in first-class condition cannot be too strongly emphasized. The inability of spark plugs to pass the bomb test has frequently been traced to the failure of the magneto to supply sufficient energy. Magnetos should be serviced periodically.

Booster magnetos may be employed for test purposes, but do not develop sufficient voltage to cause the plug to spark continuously at the higher pressures. If kept in good condition, they may be used for pressures up to 100 lb. per sq. in. It should be borne in mind that the voltage developed by this

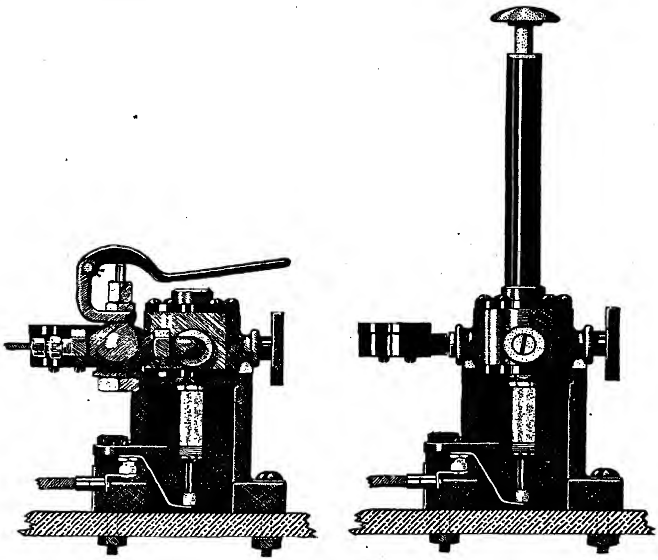


FIG. 15.—Bomb apparatus for testing spark plugs. One at left uses live-air pressure. At the right is one with a hand pump for portable use, but it can be used on pressure lines. It is tested to stand 300 lb. pressure; has 200 lb. gage.

type of magneto varies with the speed at which it is operated. If a hand crank is used, plugs may appear to miss occasionally as it is difficult to maintain the speed sufficiently high for any appreciable time.

Spark coils should not be used for testing mica spark plugs. The results obtained are misleading. It is possible to damage the plug insulation with this type of equipment.

The group of three-point gaps illustrated in Fig. 16 is used to dispose of the spark energy in the magneto leads not used for the test. Flashover inside the magneto and burning of the distributor block are avoided by the use of a separate gap for each unused lead. Difficulty may be encountered with the magneto if the unused leads are bunched together on one gap. A copper strap on the back of the mounting panel connects all of the upper row of adjustable "ground" points of the gaps together. This strap is in turn con-

nected to the frame of the magneto and the frame of the test bomb. The third point of the three-point gap is known as a "teaser point." It is insulated from the others and has no wires connected to it. Dimensions of gap parts are illustrated in Fig. 16. The magneto manufacturer's recommendations should be followed for the setting of gaps.

A push-button type of switch with circuit normally closed (refrigerator door switch) should be connected between the primary circuit and the magneto frame to provide control of the spark. Until depressed, the "normally closed" type of push-button switch keeps the magneto "grounded."

Carbon dioxide and nitrogen gas are most commonly used for supplying pressure to the test bomb. They are economical, convenient to handle and readily obtainable in steel containers. They are dry gases and eliminate test irregularities introduced when moisture is present as is frequently encountered when compressed air is used. Although not so desirable, the bomb can

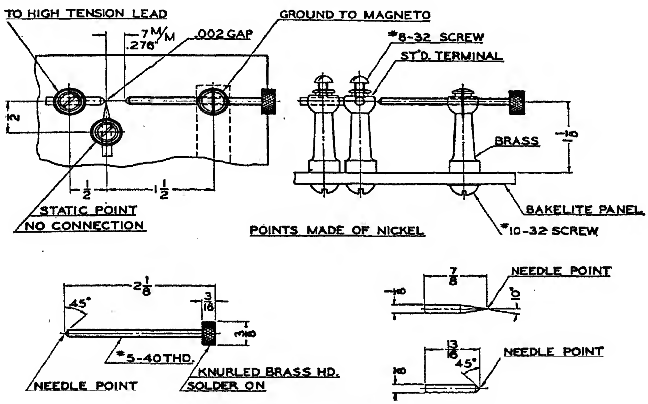


FIG. 16.—Details of spark-gap construction.

be connected to a compressed air tank. However, the air must be kept free of moisture. A water separator, such as used with air brushes, should be installed in the line close to the bomb. It should be drained frequently. A regulator is necessary when a carbon dioxide or nitrogen tank is used.

The presence of moisture will give misleading results.

Bomb Test.—Plugs should be tested under pressure. Testing in open air is unreliable since it is not comparable with the operation in an engine; a plug that fires in open air may not function in an engine. Testing under pressure provides evidence of the electrical condition of the spark plugs.

Practice is required to determine correctly when a plug fires regularly in a bomb. With the B G four-point shell electrode, the spark "hunts" around from one electrode point to another, firing across the point having the least resistance at the instant. To an inexperienced operator this "hunting" might appear to be a "miss."

The amount of electrode clearance has a direct bearing on the ability of the plug to fire at various bomb pressures. Clearances of less than 0.012 in. are not recommended for present-day operation. When plugs appear

unsatisfactory during the bomb test, check the electrode clearance for proper setting of 0.012 or 0.015 in.

On shielded plugs, a "miss" is frequently caused by the presence of dirt or moisture in the barrel of the plug or on the surface of the test lead inside the plug.

Plugs should be permitted to spark in a bomb under pressure for 15 sec. A shorter period cannot be relied upon to provide a satisfactory test; longer periods are unnecessary.

Test pressures of 125 lb. per sq. in. with gaps not exceeding 0.015 in. have been found satisfactory; for engines of high specific power output, 150 lb. per sq. in. are generally used. Occasionally somewhat higher pressures are employed.

Bomb testing is readily accomplished:

Screw the plug firmly into the bomb.

Apply the high-tension lead from the magneto to the spark-plug terminal.

Close the "relief" valve on the side of the bomb.

Apply pressure to the bomb by opening the "pressure" valve. Pressure in the bomb will be indicated on the gage. If a hand-pump type of bomb is used, operate the pump until the desired pressure is obtained.

Press the push-button switch controlling the magneto.

Through the glass window in the top of the bomb observe the plug sparking; it should spark continuously at the test pressure.

Open the "relief" valve at the side of the bomb to release the pressure.

Remove the plug.

Gasket, Spark Plug, Engine.—Solid copper gaskets aid in reducing spark-plug temperatures in engines of high specific power output. They become hard in service and should be annealed for repeated use. They should never be used if they are distorted, scored, or burred; gas leakage will result. The respective engine manufacturer's specifications for spark-plug cylinder gaskets should be followed.

Elbow Assembly, Spark Plug.—To avoid difficulty, spark-plug elbows, used with shielded spark plugs, must be properly assembled on the ignition harness. Details to be followed for correct assembly are illustrated in Fig. 17.

Elbows used with the manifold type of ignition harness are provided with a taper seat at the point of attachment to the harness to accommodate a rubber or composition gasket. Difficulty may be encountered by the entrance of moisture, should this gasket be omitted, or if there is insufficient tension to seal the joint properly. However, too much compression of the taper gasket at this point must be avoided to prevent damaging ignition wire insulation. With elbows designed for use with individually shielded ignition wires, care must be exercised to seat the lead cone properly at the rear of the elbow after the metal shielding braid has been properly folded back. Failure to do this may result in interference to radio reception.

Terminal Sleeve.—Particular care should be exercised in applying the terminal sleeve to the wire. Flashing may occur inside the sleeve if the insulation is cut too far back from the end where the wire passes through the eyelet in the sleeve. This will result in a misfire of the plug and may lead to fouling. The end of the insulation must bear firmly against the brass disk on the inside of the end of the sleeve.

The ends of ignition wires constructed with a layer of cotton under the lacquered surface should be dipped in an insulating varnish for about 1 in. and permitted to dry before terminal sleeves are applied to the wires. This

treatment prevents the layer of cotton from acting as a wick, should moisture find its way into the assembly. Moisture creepage is thereby retarded and the tendency for flashing along a moisture path is reduced.

Spark-plug Installations.—The spark-plug bushings in the cylinders of the engine should be thoroughly cleaned with a small round brush to remove any oil or grease deposit from the threads; otherwise, this may be forced ahead of the plug as it is screwed into place and accumulate on the electrodes, preventing the plug from functioning. *Use a brush having soft copper wire or stiff hair bristles. Do not use a steel wire brush.*

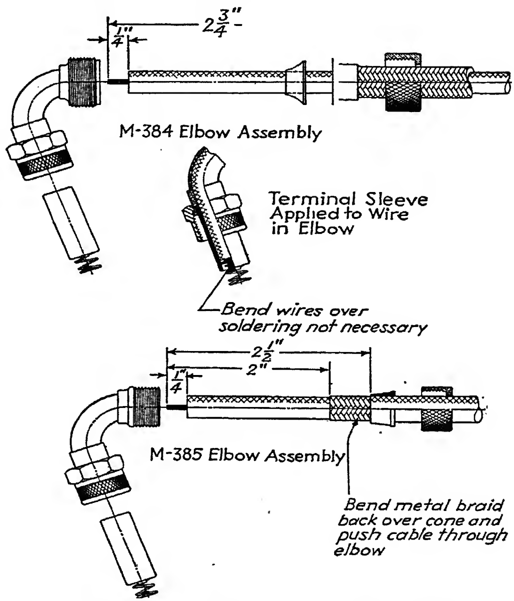


FIG. 17.—Elbow assembly of two types of plug.

A light coating of B G mica thread lubricant should be applied to the plug threads before they are installed in the engine.

Wrenches with handles more than 10 in. long should not be used for installing spark plugs in an engine. It is possible to distort the spark-plug shells and cause the cores to loosen when too much force is used; the pressure exerted should not exceed 500 in.-lb. (approximately 40 ft.-lb.). The engine manufacturer's torque limits should be consulted. *These limits should not be exceeded.*

Plugs should not be pulled down too tightly when solid copper gaskets are used, as the bronze cylinder bushing may be damaged when removal is attempted. This is particularly true when plugs are installed in a hot engine.

When copper asbestos gaskets are used, the plugs may be pulled down slightly tighter without danger of injuring the cylinder bushing. It is good practice to retighten the plugs after the first few hours of engine operation.

Shielded spark-plug elbows should not be pulled down too tightly. The plug core may be loosened in the shell when an attempt is made to back off the elbow connection nut.

A small copper gasket, which has been annealed to dead soft, should be used between the end of the barrel on shielded spark plugs and the elbow assembly to prevent the entrance of moisture. *This is important; otherwise, moist air may be drawn into the plug as the engine cools and condensation result.* A new gasket should be installed each time.

When tightening the elbow connection, the ignition wire or cable should be held so that any strain exerted by it will tend to tighten rather than loosen the plug.

Irregularities, Fouling.—Fouling of spark plugs may occur after starting a cold engine, owing to an excess of oil in the cylinders. A gradual clearing out usually takes place as the engine warms up.

Fouling may also be caused by permitting engines to run at slow speeds for long periods of time, either on the ground or in the air. When fouling has occurred from this cause, operation of the engine at or near normal rated speed for short intervals will in most cases assist in clearing the fouled plugs.

New or overhauled engines that have been treated for storage usually contain heavy oil or a compound to prevent rusting. It is difficult to remove all of this from the cylinders by draining. Under these conditions, during the initial run-up, the spark plugs have a tendency to foul. Operation of the engine at higher speeds, until it has had an opportunity to clean out thoroughly, will be found helpful.

Engines consuming excessive quantities of oil will be found more readily to foul spark plugs, even under operating conditions.

Plugs in engines that have been standing idle for long periods may become loaded with oil due to seepage in the cylinders, particularly the lower cylinders on radial engines and engines of the inverted type.

Irregular performance of shielded spark plugs may be caused by an accumulation of an oil film or dirt in the upper barrel.

Spark plugs that have become inoperative from these causes may be cleaned by degreasing or rinsing in clean unleaded gasoline. The plugs should be permitted to dry before being reinstalled. *In cases of this kind, disassembly of the plugs is not usually necessary.*

During damp weather, or when the humidity is high, condensation may occur and seriously affect the functioning of the entire ignition system. This includes the magneto, ignition harness, and spark plugs. Generally, condensation occurs with sudden changes of temperature. Throttled engines on a descending airplane cool rapidly. The temperature under the cowling is also lowered. This change of temperature is frequently sufficient to condense the moisture contained in the air within those parts of the ignition system mentioned.

Moisture in any part of the ignition system may provide an undesired path for the high-tension current to follow. When this occurs, misfiring of a spark plug may result. Continued misfiring will cause fouling. When found in this condition, it is natural to assume that the plug was at fault. Replacing the plug frequently appears to correct the condition; whereas moisture in the remainder of the ignition system may have been originally responsible and dried out meanwhile under the heat of the engine.

Moisture frequently accumulates on the terminal sleeve of shielded plugs. *It is important to check terminal sleeves inside as well as outside.*

Owing to the presence of moisture, plugs frequently do not test satisfactorily immediately after their removal from an engine They should be dried out or stored in a warm dry place before further tests are attempted.

When shielded plugs are suspected of having become inoperative owing to the presence of moisture, they should be heated to 250 to 300°F. for 2 hr. or more to eliminate any moisture. If an oven is not available, a container that can be heated over a burner will serve the purpose. A screen arranged to keep the plugs above the bottom of it will prevent localized heating and permit the heat to be more uniformly distributed. Plugs should be tested, after cooling to room temperature.

Returning Plugs to Factory.—Cores or plugs returned to the factory for retipping or general reconditioning should be carefully packed. A wooden rack comprising a top and bottom with suitable sized holes, as illustrated in

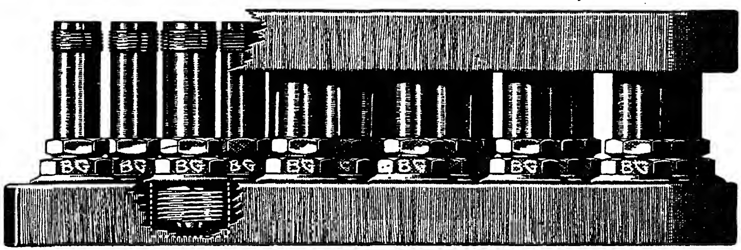


FIG. 18.—Tray for shipping and storing plugs.

Fig. 18, will prevent damage during shipment. This rack also provides an excellent and convenient means for storing plugs.

Cores or plugs returned for service should be accompanied by a packing slip carrying instructions as to the nature of the repairs desired.

All large makers of spark plugs have developed special tool kits for the mechanics who service their plugs. It is advisable to use the tools that have been developed in this way. For, although all spark plugs in general use have much in common both in design and construction, there are differences that make these special tools advisable. The plugs described and illustrated are taken as typical examples of those in general use in airplane engines.

SERVICING CHAMPION SPARK PLUGS

It is essential that an aircraft engine be fitted with the proper type of spark plug, and reference should always be made to the spark-plug manufacturer's recommendation chart before installing. Abnormal engine conditions or special operating conditions may require a different type of spark plug. This is not the fault of the plug, and a correction of the engine condition or use of a plug type suited to the particular operating condition is needed to obtain the desired performance. The Champion Spark Plug Co. will cooperate with aircraft maintenance men and owners in any of their spark-plug problems, and welcome letters of inquiry, which will receive prompt attention.

Installation.—In many cases mechanics use entirely too much force in tightening aviation plugs into cylinder heads; this may seriously injure the

plug. The maximum pressure to be used in tightening plugs into cylinder heads is 40 ft.-lb. There are wrenches now on the market that indicate the pressure used in tightening in foot-pounds. This is a step in the right direction, as many mechanics seem to feel that everything, including spark plugs, should be tightened up to their maximum, regardless of the strength of the parts involved, or of the variations in the length of the wrench handle, or of individual strength.

Gaps.—Gaps on new plugs are set at 0.015 in. They should be checked at regular intervals, depending upon the type of engine and the service, and should be reset when they become too wide, that is, 0.020 to 0.025 in. Gaps can be reset by pushing in the prongs of the ground electrode against a round wire gage. Never attempt to move the center electrode, as doing so might cause injury to the primary mica insulation. Gaps should be measured with a round wire gage inserted between the electrodes and parallel to the center electrode.

Reconditioning.—When mica aircraft plugs are to be reconditioned, they should first be tested in a spark-plug pressure tester and should spark up to 110 lb. If the primary insulation has become fractured, the spark will not jump the gap but will leak through the broken insulation and, of course, the plug cannot be reconditioned.

Sometimes if the plug is badly fouled, it will spark over the surface of the firing end insulation or jump from the insulation to the shell. This will usually be remedied when the core has been cleaned up.

After the plug has passed its first test, it should be disassembled, with the proper size wrenches or fixtures and the parts carefully placed in individual racks. The firing end of the insulator may be cleaned with garnet cloth. The center electrode should be dressed down to make it round again, but should not be reduced in diameter to less than 0.100 in.

Care should be taken not to reduce the head of the center electrode where it abuts the mica insulation; and the mica insulation, itself, should not be turned down, as this might destroy the plug and would certainly affect its operation and life.

The side electrodes on the shell may be cleaned with a wire brush to remove carbon and fuel deposits. They may be cleaned in gasoline or some solvent to remove rust and grease. The shell should then be pushed on an arbor of 0.160-in. diameter so as to open the side electrodes for resetting the gaps.

Before the core is reassembled into the shell, it should be tested for electrical current leakage or corona.

Corona.—Corona is electrical current leakage within the mica insulation and paralleling the center electrode of the spark plug. It is visible through the translucent mica core and obviously impairs the spark at the gap. Presence of corona is often the cause of hard starting, missing at high speeds, fouling, and rough idling.

Test for Corona.—The test for corona, which is suggested and which is similar to that used by the U.S. Army Air Corps, is as follows: the core is removed from the plug and placed with its firing tip half the length of insulation at the firing end away from a grounded point. As an example, the gap between the firing tip of the Champion M3-1 and the grounded point should be $\frac{3}{16}$ in., as the length of the firing end insulation in this particular type is $\frac{3}{8}$ in.

The spark is jumped across this gap, either coil or magneto being used as a source of current. The test is made at atmospheric pressure. If corona is present, it can be seen as a streak of light inside the mica washers that form

the core. Corona should not be confused with flashover, which shows as an arc over the outside surface of the mica.

Reassembly.—The insulator should then be reassembled into the shell, using a mica base grease on the inside threads and a new inside gasket. Here again, the amount of pressure used in reassembling the plug should be carefully watched. It takes about 22 ft.-lb. to assemble the plug properly and seat the inside gasket so that the joint will be gastight in service; the maximum pressure to be used is 25 ft.-lb.

Tools, for assembly and disassembly, are made by several concerns.

After the insulator has been reassembled into the shell, the gaps should be reset to 0.015-in. and the plugs should be spark-tested at 150 lb. pressure. While in the spark tester, oil or water may be squirted in the joint between the bushing and the shell to test for leakage. Bubbles will show if leakage occurs. No leakage can be allowed; those plugs that show leakage should be rejected, to have the core gaskets replaced or defective parts rejected, as the case may require.

When plugs are removed from the engine and reinstalled, new solid copper outside gaskets should be used at regular intervals. Continued removal and installation using the same outside solid copper gasket will cause the copper to harden or the gasket to be slightly distorted. This results in gas leakage between the spark-plug cylinder head bushing and the plug. Such leakage means that the plug will run at a higher temperature than normally, which will shorten its life and may seriously injure it.

Champion mica aircraft plugs may be returned direct to the factory for reconditioning.

SECTION XIII

ENGINE STARTERS

There are several types of starters used on airplane engines. The simplest is the hand turning gears for engines up to 600 hp. in planes not equipped with batteries or generators. These consist of gear reduction units which operate an automatic engaging and disengaging mechanism through an adjustable torque overload release. These starters are available with various gear ratios for use on engines up to 600 hp. but are not generally used on engines as large as this. They have a suitable hand crank and whatever extensions may be needed.

Combination Starters.—The Eclipse inertia starter stores energy in a small flywheel by accelerating it to a very high speed, either by hand or with a motor. The energy stored in the flywheel is transmitted to the engine crankshaft through reduction gearing, a multiple-disk clutch and driving jaws controlled by a suitable engaging mechanism. Starters of this type are available for either hand or electric power and in 12 or 24 volts, grounded or insulated, shielded or unshielded; they handle engines up to 2,000 hp. Hand cranks are furnished in all cases.

Direct Cranking Starters.—These are electric starters with a motor, a gear reduction, and a mechanism that automatically engages or disengages through an adjustable torque overload release. The engine is cranked directly by the starter without preliminary storage of energy as in the case of the inertia starter. They provide instantaneous and continuous cranking, and are for engines up to 1,500 hp.

Direct Cranking Electric and Inertia Starters.—These operate the same as the inertia starters already mentioned, except that the circuit to the motor remains after engagement of the starter clutch with the engine crankshaft. In this starter the energy stored in the flywheel is used to overcome the initial, or "breakaway," torque of the engine. After this the motor gives continuous cranking of the engine as in the case of the direct cranking starter. These are made for 12 or 24 volts, grounded or insulated, shielded or unshielded, as with the direct cranking starters. They have hand cranks for emergency use and handle engines up to 1,500 hp.

Cartridge Starters.—This type of starter uses the concentrated energy stored in a cartridge, which goes in a loading breech mechanism and is fired by electric contact. The cranking effort is applied to the crankshaft by means of a piston and a screw shaft arrangement which turns the crankshaft when the cartridge is fired. These starters have no provision for hand starting. They are used in engines up to 1,000 hp.

Starters operating on this principle, shown in Figs. 7 and 9, are made by the Breeze Corp., Newark, N.J., and by Eclipse Aviation, Bendix, N.J.

ECLIPSE HAND AND ELECTRIC INERTIA STARTERS

Installation and Maintenance.—These starters are so commonly used that a few suggestions by the makers should be both interesting and valuable to all who handle them.

Starters left in storage for 6 months or more should be thoroughly cleaned, relubricated, and tested before installation. Failure to do so allows dried-out lubricant to remain in the starter, makes hand cranking difficult, and results in a loss in starter performance.

Starter.—Before mounting the starter on the engine, remove the cover over the starter jaw. To install the starter, remove the engine crankcase plate and gasket covering the starter drive and mounting flange. See if the engine jaw and starter jaw are of the same type and are of the correct rotation for proper engagement. With the engine gasket removed, the distance from the mounting flange to the outermost part of the engine jaw must be $1\frac{1}{16}$ in. ± $\frac{1}{16}$ in. The clearance between the engine jaw and starter jaw must be $\frac{1}{32}$ in. min. when the latter is fully retracted. Wipe the engine mounting flange clean and replace the gasket. The starter mounting flange has 24 holes that permit locating the starter at 15-deg. increments to facilitate clearance of structural members. It is shown in Fig. 1.

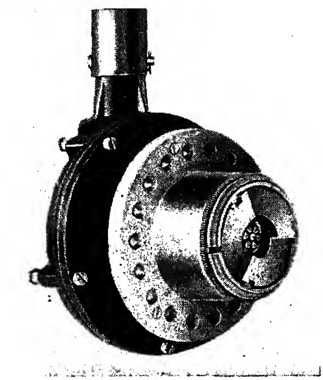


FIG. 1.—Eclipse hand engine starter.

Starter Hand Crank Housing Position. In addition to the 24 available positions of the starter, the hand crank housing may also be rotated in steps of 15 deg., which permits further adjustment of hand crank position within 90 deg. to the right of its vertical position (facing starter rear) and to the left, within 120 deg. It should be noted that if the hand crank rotation on a clockwise starter is clockwise (facing the end of the crank collar) and the hand crank housing position is moved to the left of the vertical center line, *the operator's position with respect to the propeller is incorrect when cranking the starter.* The starters are designed so that hand crank rotation may be changed by simply altering the position of the cranking pinion on the crankshaft in the crank housing as instructed below. The following four possible combinations of starter and hand crank rotations are available:

Clock rotation jaw (facing the starter rear) with clock rotation crank (facing the end of the crank collar)
Clock rotation jaw with counterclock rotation crank
Counterclock rotation jaw with counterclock rotation crank
Counterclock rotation jaw with clock rotation crank

Note: In the event that the opposite crank rotation is desired, unscrew the four hand crank housing through-bolts sufficiently to separate the crank housing from the starter. Remove the crankshaft nut and slide out the crankshaft and collar assembly. Interchange positions of the pinion and spacer. Reassemble the unit, replacing the cotter pin and safety wire. **Caution.** If the installation utilizes the helical slot (detachable hand crank and extension) instead of the through-bolt (extension bolted to the collar), it is necessary to replace the crankshaft and collar assembly with one having the opposite helix in order to provide the proper engagement of the extension with the crank collar.

Hand Crank and Extension.—The hand crank extension furnished with each starter consists of a rod having a pin at the tapered end and a sleeve that must be assembled to the rod and a pin. The sleeve contains a helical slot and two holes, one of which is drilled *through one side* and the other *through both.* Determine the length of extension required and cut the rod to the desired length, allowing for the fact that the rod must be inserted a distance of 1¼ in. in the sleeve. Make certain the helical slot is correct for the rotation required, then assemble the sleeve to the rod using the hole drilled through one side of the sleeve. Drill through and ream to a dimension of 0.250 in. plus 0.001 in. minus 0.000 in. Insert a pin flush with the outside diameter of the sleeve. To complete the installation, an external mounting support bearing is required, the mounting location of which determines the method of installing the hand crank and extension.

If the bearing support is mounted on a structural part of the airplane, the hand crank and extension should be assembled together as follows: Press out the pin in the hand crank and bolt the extension assembly to the hand crank, using the hole from which the pin was removed and the bolt and nut furnished with the crank collar of each starter. The hand crank and extension assembly are then detachable as a unit. If, on the other hand, the bearing support is mounted directly on the engine so that the starter and extension are free to move as a unit, the extension may be bolted to the crank collar by pressing out the pin in the tapered end of the extension assembly. Use the hole from which the pin was removed and the bolt and nut furnished with the crank collar to secure the extension to the starter.

Should the installation be such that neither of these two methods can be used, it is recommended that the external bearing support be shock mounted or a universal joint provided between the bearing support and the crank collar. Regardless of which method is utilized, a self-aligning ball bearing with provisions for lubrication should be provided in the external bearing support and applied at the outer end of the large diameter sleeve of the extension assembly. Should a plain bronze bearing be used for supporting the hand crank extension, it is recommended that the length of the bearing surface be kept as short as possible and that a clearance of 0.005 in. be maintained between the outside diameter of the extension sleeve and the inside diameter of the bearing. Care should be taken that the alignment of the extension shaft is as accurate as possible in order to facilitate hand cranking and prevent undue strain on the starter housing during hand crank operation.

Hand Starter with Booster Coil and Anticapacity Switch.—A manually operated pull cable, or rod, is required to engage the starter after the flywheel has been accelerated. The pull cable or rod is secured to either arm of the bell crank on the starter and may be installed at any convenient location on the airplane. The anticapacity switch mounted on the starter is properly connected to the bell crank and does not require any adjustment. When installing the starter controls, make certain that the engaging cables or rods have sufficient slack to permit full retraction of the starter jaw, otherwise, engine lubricating oil will leak into the starter through the oil seal and affect starter performance.

If excessive friction is present in the engaging linkage, an external spring should be added to assist in returning the starter jaw. The high-tension terminal (Fig. 2), located on the side of the booster coil, must be connected to the booster terminal provided on the engine magneto with 7-mm. high-tension cable. The terminal post of the anticapacity switch must be connected to the positive side of the battery. Remove the three cover screws of the

anticapacity switch to provide access to the terminal post. *Note:* A lead between the booster coil and anticapacity switch is furnished with the starter.

Electric Inertia Starter.—This type of starter is equipped with an integrally mounted accelerating motor, a booster coil, and a combination solenoid meshing device and anticapacity switch which are mounted on the starter by means of suitable brackets. In addition, the use of a separately mounted solenoid switch is recommended for closing the motor circuit. Electrical connections between the booster coil, meshing device, and accelerating motor are provided by the manufacturer. As the electric motor was originally designed to incorporate a built-in flat type of solenoid switch which has since been eliminated from this design by the manufacturer, an additional

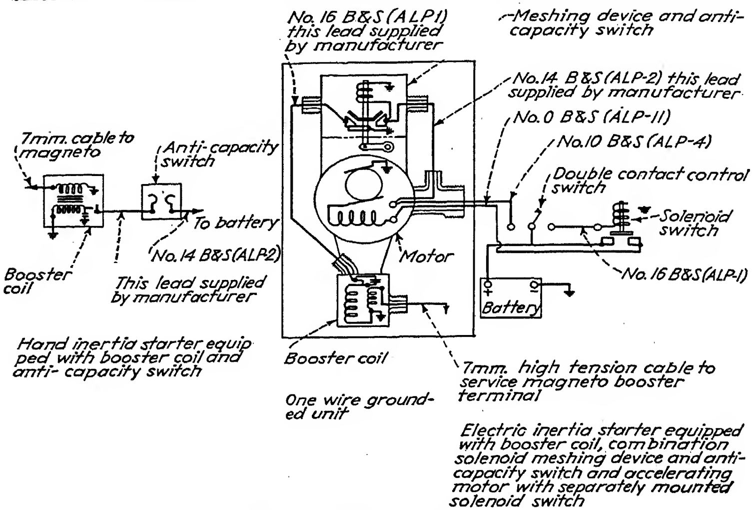


Fig. 2.—Wiring of Eclipse electric inertia starter.

dummy terminal post has been incorporated in the motor adjacent to the shielding outlet. This is shown in Fig. 3.

In view of the above and to facilitate connection of external wiring, the dummy terminal post nuts should be loosened sufficiently to permit the movement of the terminal post to one side and the connection of external wiring to the motor terminal post. After completing wiring connections, the nuts on the dummy terminal post should be tightened. On later production units incorporating this terminal post, a copper jumper has been added between the motor terminal post and the dummy post in order to permit attachment of wiring directly to the dummy terminal post. The use of the copper jumper strap is recommended to facilitate wiring connections.

The meshing device is properly engaged with the bell crank prior to shipment and does not require any adjustment at the time of installation. However, the high-tension terminal, located in the side of the booster coil, must be connected to the booster terminal provided in the engine magneto with 7-mm.

high-tension cable. The three cover screws of the accelerating motor shield must be removed in order to make connections as shown on the wiring diagram. Use the wire sizes indicated and a suitable double contact control switch in the circuit. Cable lengths in the starter circuit should be kept as short as possible to minimize voltage drop as well as to decrease the weight of cable used. All cable ends should be securely soldered to the terminals and completely covered with rubber nipples or tape to prevent accidental short circuit. The battery terminals should be covered with vaseline to prevent corrosion.

Operation.—The starting ability of an inertia type of starter depends on the energy stored in the rotating flywheel. The starter is designed to provide a flywheel speed of approximately 12,000 r.p.m., whether manually or electrically accelerated, and this speed should not be exceeded when energizing

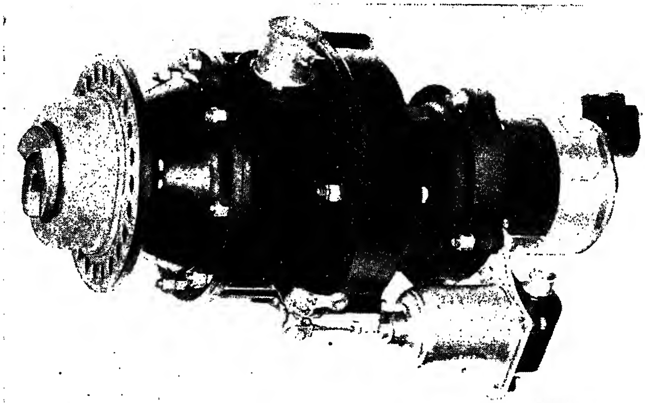


Fig. 3.—Eclipse electric inertia starter.

the flywheel. Inertia starters incorporate a protective clutch designed with alternate steel and bronze disks. The purpose of this clutch is to protect the starter during backfire of the engine or under excessive loads. In the case of a very cold engine, the energy stored in the flywheel may be dissipated to a certain extent in the clutch and the engine should by some means be loosened up, preferably by turning over the propeller by hand before the starter can be expected to function properly. For best results in starting, prepare the engine in accordance with the manufacturer's instructions.

Caution. Do not attempt to operate the starter either manually or electrically with the starter and engine jaws engaged. The engine crankshaft should be rotated two revolutions to ensure that the engine cylinders are clear of oil and to break the engine away for easier starting. The starter toggle should be returned to the disengaged position before the starter is allowed to run down completely, in case the engine fails to start. This will prevent sticking of the starter jaw.

Manual Operation.—To operate either type of starter manually, gradually accelerate the hand crank to a speed of approximately 75 r.p.m. Disengage

the crank handle and pull the control rod or cable to mesh the starter with the engine. *When using an external energizer to accelerate the flywheel, be sure to remove the energizer before engaging the starter jaws.* Return the control rod or cable to the original position upon firing of the engine. The booster coil and anticapacity switch circuit is closed automatically during the time the starter is meshed and the circuit broken when the engine starts. The starter disengagement is automatic upon firing of the engine. If the engine fails to start, repeat the foregoing procedure. **Caution.** If the engine fails to start and the starter jaw remains engaged with the engine jaw, proceed as follows: *Open the anticapacity switch circuit* by opening the battery switch or its equivalent to *make certain that the booster coil circuit is dead.* Then turn the propeller by hand (ignition off) about one-third to one-half of a revolution in its proper direction of rotation to release the starter jaw. In some cases, the starter jaw may be disengaged in starters using a pull rod by manually returning the rod to its disengaged position.

Electrical Operation.—To operate electric inertia starters, close the solenoid switch circuit for approximately 10 sec., or until such time as the starter hum becomes constant. Then open the solenoid switch and close the meshing device circuit to mesh the starter with the engine. Return the control switch to neutral position when the engine fires. The operation of the booster coil and anticapacity switch is automatic at the time of meshing the starter jaw with the engine jaw.

Service Maintenance.—When properly installed and operated, the starter should not require any attention between major overhaul periods other than the following. Starters are properly lubricated prior to shipment from the factory and should not require lubrication except at overhaul.

Motor Inspection.—After every 150 hr. of engine operation, remove the motor terminal shield cover and the window strap and examine the motor for dirty or loose connections and worn or binding brushes. Clean and tighten all connections. Replace all defective wiring. The brushes should be a free fit in the brush boxes without excessive side play. Binding brushes and brush boxes should be wiped clean with a gasoline-moistened cloth. Worn brushes should be replaced before their maximum wear limit is reached to ensure proper operation between inspection periods. The maximum permissible wear of brushes is $\frac{1}{4}$ in. from a new length of $\frac{3}{4}$ in.

When replacing a worn brush, it should be properly seated by inserting a strip of #000 sandpaper between the brush and the commutator with the sanded side next to the brush and pulling in the direction of rotation. Repeat until the brush is fully seated. **Caution.** *Do not use coarse sandpaper or emery cloth.* Remove sand or metal particles with compressed air. *If the commutator is rough or dirty, smooth with #100 sandpaper.* Check the brush spring tension and replace the spring if the tension is less than 36 oz. when compressed to a length of $\frac{7}{16}$ in. from a free length of $1\frac{5}{32}$ in. $\pm \frac{1}{32}$ in.

Starter Crank Extension Support Bearing.—After every 60 hr. of operation, the crank extension support bearing should be lubricated with engine oil.

Inspection Starter Accessories.—When properly installed and operated, the booster coil, solenoid meshing device, and anticapacity switch should not require attention between major engine overhaul periods with the exception that the booster coil contacts should be cleaned.

Service Troubles.—In order to assure satisfactory operation of electric inertia starters, the battery should be kept fully charged and the battery terminals kept clean and tight. In the event of improper operation, examine all wiring carefully and check the charge of the battery. If sufficient torque

is not developed to start the engine, the indications are that the clutch is slipping owing to worn or scored disks or leakage of engine oil into the starter interior because of a worn baffle plate oil seal. Leakage of engine oil into the starter gear case and around the flywheel will result in failure to energize the starter.

This condition may be readily determined by removing the flywheel cover of hand inertia starters, or by removing the motor in the case of electric inertia starters. Oil leakage may be due to a worn baffle plate, to meshing rod oil seal, or, in the case of hand inertia starters, to improper adjustment of the control linkage. If excessive oil or any of the above troubles is experienced with the starter, the unit should be forwarded to a service station or to the manufacturer, for inspection and test. Should the starter jaw of electric inertia starters fail to engage with the engine jaw, either the solenoid meshing device or control switch is inoperative, and replacement should be made.

Major Overhaul.—At every major engine overhaul, the starter should be removed from the airplane and forwarded to an authorized service station, or returned to the manufacturer, for overhauling. This gives a complete disassembly of the unit and involves the use of special tools and equipment available only at the above places.

Storage.—No special preparation is required prior to placing the starters in storage except that they should be individually wrapped in waterproofed paper.

ECLIPSE DIRECT CRANKING ELECTRIC STARTERS WITH INTEGRAL HYDRAULIC FEATHERING PUMPS

These suggestions apply to the Eclipse 405 and 634 E-160 direct cranking electric starters with integral hydraulic feathering pump. The units are all of the same basic construction, incorporating a standard 6-in. S.A.E. mounting flange, and differ mainly with respect to capacity rating. On insulated units, the two positive posts are housed in one shield and the common negative post in a separate shield. On grounded units, the negative post shield is omitted and the post is grounded internally. These are shown in Figs. 4 and 5.

Wiring and Accessories.—All starter pumps have three terminal posts and two sets of field coils to permit reversal of rotation for operation as a starter or a pump. The two positive posts are housed in a common shield which is stamped with the letter "P" adjacent to one post to indicate the pump field coil post and the letter "S" adjacent to the other post to indicate the starter field coil post. The third, or armature post, is the negative post and is contained in a separate shield. On grounded units the armature post shield is omitted and the post is grounded internally with a steel washer. Before making connections, examine the motor terminals to determine the system utilized and refer to the name-plate data to ascertain the proper voltage required. The same precautions should be taken when installing the accessories used with the starter. When installing grounded systems on airplanes having shock-mounted engines, be sure the engines are securely grounded to the airplane structure. Two remotely controlled solenoid switches may be used to change over from starter to pump field circuits. However, when the Hamilton standard pressure cutout switch is incorporated in the oil pressure line, the two-solenoid system should be used with the Hamilton standard push-button switch in the pump field circuit (see Fig. 6). Details regarding the installation of control switches and the booster coil, if used,

should be obtained from the instruction sheets covering the individual units. A booster coil is recommended for use with starters to supplement the spark of the engine magnetos to ensure a hot spark during the cranking period.

Tubing.—Use only aluminum or copper seamless tubing. Use a standard tube cutter. *Do not use a hacksaw. Clean all tubing thoroughly before*

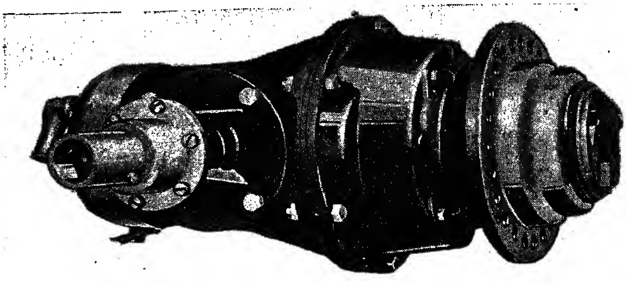


Fig. 4.—Eclipse direct cranking starter.

installing. Use Parker Threadlube on all *male* threads of tubing fittings. Do not apply thread lubricant to the female threads as particles of this material may be deposited in the tubing and subsequently in the pump, thus causing serious damage.

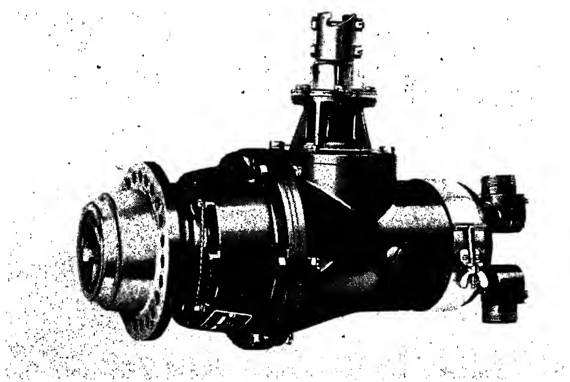


Fig. 5.—Starter for use with Hamilton feathering propeller.

Connect the inlet port of the pump, as shown in Fig. 6, to the supply tank through a suitable filter having a screen with a maximum opening of 0.003 in. The filter must either be submerged in the oil supply itself or be of air-tight construction. The supply to the pump should be drawn from the bottom of the supply tank to prevent the possible admission of air to the inlet line to

the pump. The supply tank and filter should be readily accessible for cleaning.

Connect the outlet port of the pump to the Hamilton standard constant-speed control. Refer to Hamilton standard instructions for details of installation.

Operation.—Prepare the engine in accordance with the engine manufacturer's instructions; then operate the starter switch. Engagement and release of the starter jaw are automatic and require no attention. **Caution.** Should the engine fail to start readily, the cause should be ascertained immediately. The pump should *not* operate when the starter is in operation. Operation of the pump is automatic upon closing the pump switch. When the pump is in operation, the starter should rotate backward with the jaw fully disengaged.

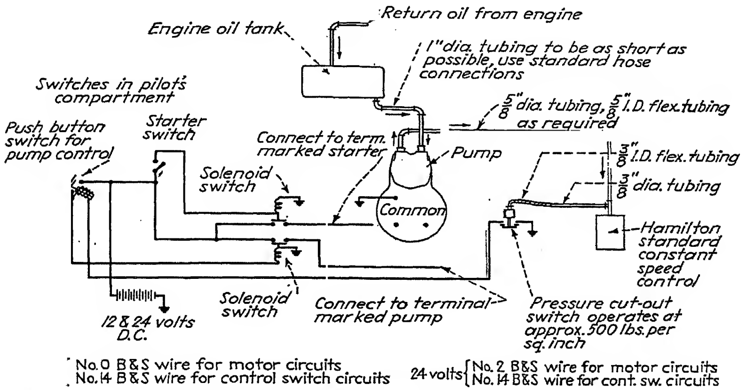


FIG. 6.—Installation diagram for wire sizes and connections.

Service maintenance and inspection are the same as for the previous starter, except that spring tension of 24 instead of 36 oz. is recommended.

Pump Inspection.—The only inspection necessary should be an occasional check on the tubing and fittings for leaks. If air is entering the inlet line, as evidenced by erratic and noisy operation, the system can be checked as follows: With the pump operating, check each joint and fitting by flowing oil around it. When the point of leakage is reached, pressure and output will immediately smooth out. Rework the fitting or joint to be air tight.

Service Troubles.—In order to assure satisfactory operation of the starter, the battery should be kept fully charged and the battery terminals should be kept clean and tight. In case of improper operation of the starter, examine all wiring carefully and check battery charge. If the starter operates but does not engage with the jaw or if insufficient torque is developed to start the engine, the indications are that the jaw friction spring is weak or that the clutch is slipping owing to worn or scored disks. Leakage of engine oil into the starter interior due to a worn baffle plate oil seal will also cause the clutch to slip. If the starter does not operate when the switch is closed and if the circuit connections are found to be in order, the trouble is probably caused by a grounded or shorted armature field coil.

If the pump runs when the starter is operating, a jammed overrunning clutch is indicated. If the pump fails to operate when the motor and gear drive are functioning, as indicated by the reverse rotation of the starter jaw, the probability is that the pump shaft has been broken. In either case the unit should be forwarded to a service station or returned to the manufacturer for overhaul. Low output pressure or capacity may be due to insufficient oil supply, low setting of the relief valve, a leak in the line, valves, or fittings, low operating speed, or the use of an improper fluid. It may also be caused by thinning out of fluid due to temperature rise. Some adequate means should be provided to maintain the fluid temperature at 140 to 160°F.

Air leaks in the pump inlet lines will cause erratic output or pressure. If the pump overheats, it may be caused by sustained operation at high pressure or by worn or binding parts. If a check of the operating cycle does not indicate overloading, the pump should be replaced. If any of these troubles are experienced, the starter or pump should be sent to a service station for inspection and test.

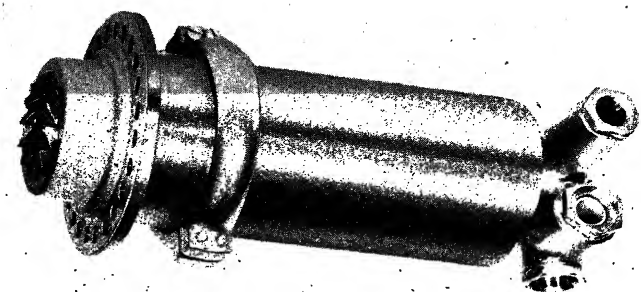


FIG. 7.—Breeze cartridge-type starter.

Major Overhaul.—At every major engine overhaul, the starter-pump and associated accessories should be removed from the airplane and forwarded to an authorized service station, or returned to the factory for overhauling.

Storage.—Before placing a starter pump in storage, all excess oil should be drained and it should be dismounted from the starter by removing the pump mounting nuts and pulling out the entire pump assembly to disengage the pump shaft from the overrunning clutch. The pump should then be thoroughly cleaned with gasoline, *clean* carbon tetrachloride, or some other suitable solvent. To clean the pump, fill it with solvent and rotate the shaft by hand at least 25 revolutions. The oil seal chamber should also be removed and thoroughly washed. Drain the pump and repeat to make certain that the inside of it is entirely clean. Fill the pump with a neutral oil such as Gargoyle D.T.E. Grade BB Oil, Standard Oil Company of New York, or an equivalent. Turn the pump shaft by hand to permit the oil to flow through the pump; then plug up the ports and wrap in waterproof paper.

The starter requires no special attention before storage except that a cover plate should be placed over the pump mounting flange to prevent dirt and foreign matter from entering the overrunning clutch and driving gears. The starter should be wrapped in waterproof paper and stored in a dry, cool place.

BREEZE CARTRIDGE ENGINE STARTER

This is a lightweight starting device that secures its power for turning the engine over from the explosion of a cartridge in a special mechanism.

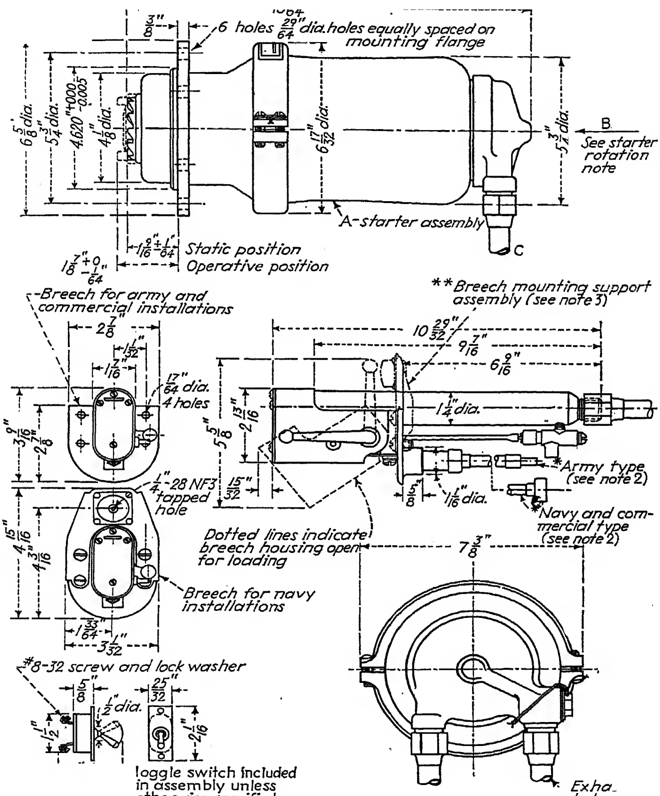


Fig. 8.—Details of Breeze cartridge-type starter showing installation dimensions.

The back end of the engine crankshaft must have a 12-toothed clutch jaw to match that of the starter; this can be furnished by the engine builder.

The firing mechanism is located below the engine and connected to the starter by a tube which should not be over 54 in. long; 30 in. is the recommended length. The slow-burning powder used generates power which is led to a small turbine on the shaft carrying the clutch jaw, and spins the engine rapidly to start it. No booster magneto is required and the necessity

for priming is also considerably reduced. Since the cartridge is fired by a small flashlight cell, there is no drain on batteries. See Fig. 7.

These starters come in three sizes: for engines up to 1,500 cu. in.; from 1,500 to 3,000 cu. in.; and for larger engines. These cover all the engines in common use. Details of the installation methods and dimensions are given in Fig. 8.

The mechanism requires lubrication and service only at the time of major engine overhaul.

ECLIPSE CARTRIDGE STARTERS

There are two designs of these cartridge starters. They are basically the same but type I has a mounting flange integral with the cylinder; in type II the flange is part of the front head and is held on the cylinder with a clamp ring. In type I the intermediate head is held in position by splines machined on the inside diameter of the cylinder and held from lateral movement by a retainer threaded into the cylinder. The intermediate head in type II is clamped between the flanges of the front head and cylinder and doweled to the front head flange to prevent turning. The screw shaft thrust bearing in the type I starter is of the ball-and-race type, one race being supported by the intermediate head retainer and the other by the screw shaft thrust sleeve. In type II the plain-type thrust bearing is supported in the front head.

Torque is applied to the engine crankshaft by means of a piston and screw shaft arrangement actuated by the release of energy stored in the cartridge. Steel balls form the bearing between the screw shaft and the internally threaded piston sleeve, and between the *external splines on the piston sleeve* and the *internal splines on the intermediate head,* to reduce friction to a minimum. The gases of combustion, released by the ignition of the powder in the cartridge at the breech, reach the starter through connecting tubing. They enter the starter through an intake housing which incorporates a safety valve in the form of a thin copper disk backed with asbestos. The safety disk is designed to blow out when pressures in excess of those normally required to operate the starter are built up in the tubing and cylinder thereby releasing the pressure through the exhaust tube. Each disk is identified by a number stamped on the metal face, the number representing the pressure at which the disk is designed to rupture. Disks stamped with the number "40" will rupture at approximately 4,000 lb. per sq. in.

The initial movement of the piston forces the screw shaft forward without rotating due to the action of two spring loaded balls on the end of the exhaust valve rod actuated by the piston. The balls are pressed into a groove on the inside diameter of the screw shaft and push it forward until engagement of the starter jaw is made. Then the steel balls snap out of the groove and rotary motion begins. A 12-toothed jaw (*A*, Fig. 9) is splined to the screw shaft and is free to move and rotate with the shaft. Should the starter jaw teeth butt against the engine jaw teeth, the thrust on the screw shaft causes it to move up to its full position against a ball-bearing-supported thrust sleeve, compressing a spring between the end of the screw shaft and the starter jaw.

At this point, further longitudinal movement of the piston is transformed into rotary motion of the screw shaft and jaw. As soon as the point-to-point contact of the jaws is relieved, the spring snaps the starter jaw into mesh and the crankshaft of the engine is rotated. The actual rotation of the starter jaw is only three-quarters of a revolution during the complete operating cycle of the starter. However, the torque imparted to the engine crankshaft

during this period is sufficient to crank the engine at a relatively high speed and through sufficient revolutions to effect a start.

When the piston is within a predetermined distance from the end of its allowable stroke, an exhaust valve, actuated by the piston, opens and allows the gases to exhaust to the atmosphere. The piston, thus relieved of the gas pressure, returns to its original position owing to the action of a heavy helical spring, which closes the exhaust valve and retracts the screw shaft and jaw. To reduce the possibility of "blow-by," starters have a seal consisting of asbestos packing rings located around the lower edge of the piston on the

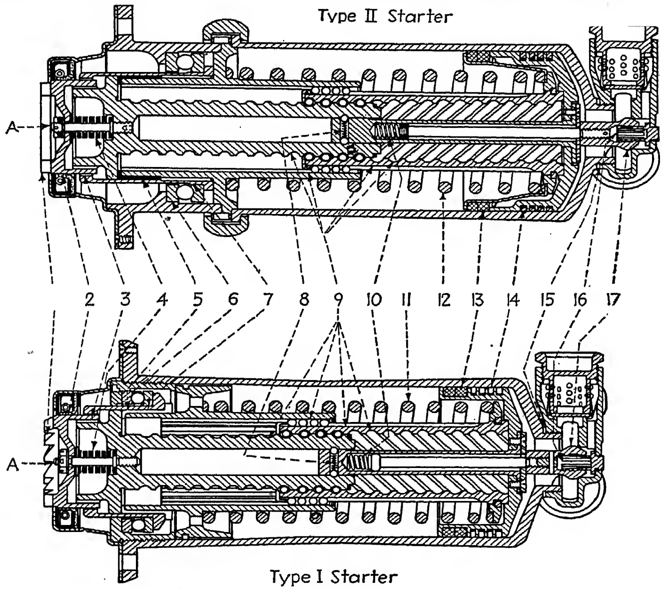


Fig. 9.—Sections of Eclipse cartridge starter.

type I starter, and contained in a retainer which is assembled to the threaded sleeve and spring assembly on the type II starter.

A baffle plate oil seal assembly incorporated on the mounting flanges of both starters prevents leakage of engine oil into the starter housing.

Breech.—The cartridge breech is of the single-cartridge, bolt-action type and includes a hinged block which carries the contact pins used to complete the electrical circuit for the firing of the cartridge. One pin is fixed and makes contact with the external circuit when the breech is closed. The other pin, located in the center of the block, is operated by a screw collar and gear sector actuated by the locking bolt. When the breech is opened, the pin recedes into the block and does not move out to its full position in contact with the cartridge shell until the breech is fully closed and locked. This prevents accidental or premature ignition of the cartridge.

The breech barrel is machined from a steel forging and incorporates a slightly tapered bore to assure a tight fit for the cartridge. The combustion chamber is attached to the breech by screw threads on the end of the barrel. The laminated shim spacer between the chamber and barrel may be varied in

Table 1.—Tolerances on the Main Parts of Hand and Electric Inertia Starters

Description of part	New fit	Serviceable limit
Flywheel jaw teeth leading edge radius (all starters)		1/16
Flywheel ball bearings:		
I.D. (all starters)	0.0001L–0.0006L	0.002L*
O.D. (all starters)	0.0001L–0.0006L	0.002L
Flywheel pinion in flywheel:		
Series 6, 11, and 11A	0.0001L–0.0007L	0.002L
Series 7 and 7A	0.0000T–0.0008L	0.002L
Backlash-flywheel pinion to crown gear, Series 7 and 7A	0.017 –0.018	0.035
Crown gear on countershaft, Series 7 and 7A	0.0001L–0.0007L	0.002L
Countershaft O.D. at roller bearing, Series 7 and 7A	0.4990 –0.4495	0.4952 min.
Countershaft roller sleeve O.D., Series 7 and 7A	0.0015T–0.0005T	0.000L
Countershaft roller bearing race I.D., Series 7 and 7A	0.8750 –0.8760	0.8798 max.
Countershaft ball bearing O.D., Series 7 and 7A	0.0001T–0.0007T	0.002L
Countershaft ball bearing I.D., Series 7 and 7A	0.0002T–0.0004L	0.002L
Bell gear ball bearing:		
O.D., Series 6, 11, and 11A	0.0005T–0.0000L	0.0015L
I.D., Series 6, 11, and 11A	0.0002L–0.0007L	0.0015L
O.D. (flywheel end), Series 6, 11, and 11A	0.0005T–0.0003L	0.002L
I.D. (flywheel end), Series 6, 11, and 11A	0.0000T–0.0007L	0.002L
Planetary pinion ball bearing:		
I.D., Series 7 and 7A	0.0001T–0.0005L	0.002L
I.D. Series 6, 11, and 11A	0.0002L–0.0007L	0.002L
Ball races in front housing (all starters)	0.002T –0.0015L	0.003L
Clutch barrel in ball ring (all starters)	0.001L –0.003L	0.005L
Crankshaft O.D. at roller bearing, Series 7 and 7A	0.6240 –0.6245	0.5202 min.
Crankshaft roller race:		
I.D., Series 7 and 7A	1.0000 –1.0010	1.0048 max.
O.D., Series 7 and 7A	0.0015T–0.0000L	0.000L
Crankshaft ball bearing:		
I.D., Series 7 and 7A	0.0001T–0.0006L	0.002L
O.D., Series 7 and 7A	0.0002T–0.0008T	0.002L
O.D., Series 6, 11, and 11A	0.0003T–0.0005L	0.002L
Crankshaft ball and roller bearing, I.D., Series 6, 11, and 11A	0.0001T–0.0006L	0.002L
Crankshaft roller bearing, O.D., Series 6, 11, and 11A	0.0008T–0.0000L	0.002L
Driven cranking gear ball bearing:		
O.D., Series 7 and 7A	0.0007T–0.0002T	0.002L
I.D., Series 7 and 7A	0.0001L–0.0006L	0.002L
Sun gear I.D. at roller bearing, Series 7 and 7A	1.0000 –1.0010	1.0048 max.
Sun gear bushing in sun gear, Series 6, 11, and 11A	Press fit	0.000L
Crank gear on crankshaft, double "D" wear limit (all starters)	0.0005T–0.0010L	1/64 in. rotation of gear at outer edge
Driven gear in barrel, double "D" wear limit, Series 7 and 7A	0.002L –0.004L	1/64 in. rotation of gear at outer edge
Driven gear on barrel:		
Double "D" wear limit, Series 6, 11, and 11A	0.0005T–0.0010L	1/64 in. rotation of gear at outer edge
"Square" wear limit, Series 11	0.0005T–0.0005L	1/64 in. rotation of gear at outer edge
Driven gear O.D. at roller bearing, Series 7 and 7A		0.6202 min.

* The letters L and T mean "loose" and "tight" by the amount shown.

thickness to allow the chamber to be rotated to any desired position at the time of installation. An ejecting mechanism, which operates when the breech is opened, ejects the exploded cartridge far enough so that it may be easily removed.

An automatic pressure-relief mechanism is included in the breech to provide for releasing any gases under pressure in the breech and tubing before the breech is opened after firing a cartridge. The relief mechanism consists of a spring-loaded ball, actuated by a rod operated by the locking bolt.

SERVICING ECLIPSE STARTERS

Control Switch.—An Eclipse control switch used in conjunction with either type of installation is of the single-contact, push-button type. A bushing of insulating material, with a metal band around one end, is assembled on the operating shaft between two flat spring contacts mounted in the switch housing. When the switch is operated, the metal band around the bushing comes between the spring contacts and completes the electrical circuit. When the push button is released, a return spring incorporated on the operating shaft returns the switch to its normal open circuit position.

Major Overhaul.—After 320 to 460 hr. of engine operation or after 500 cartridges have been fired, if this quantity of starts is accomplished in less than this period, it is recommended that the starter and breech be completely disassembled, cleaned, inspected, and overhauled. It is recommended that the starter and breech should be disassembled sufficiently to clean carbon coated parts after much use. Special tools for this work are obtainable from the makers. Table 1 gives the main tolerances.

Table 2.—Tolerances on Main Parts of Types 405 and 634

Description	New fit	Serviceable limit
Motor housing ball bearing:		
In housing	0.0008T–0.0000L	0.002L*
On armature	0.0000T–0.0007L	0.002L
Ball bearings:		
In intermediate housing	0.0008T–0.0000L	0.002L
On intermediate gear shaft	0.0000T–0.0007L	0.002L
Drive pinion in double row ball bearing	0.0001T–0 0006L	0.002L
Double row ball bearing in intermediate housing	0.0004T–0 0004L	0.002L
Planetary pinion ball bearing on stud	0.0002L–0 0007L	0.002L
Front ball race in housing	0.003T –0 000L	0.003L
Rear ball race in housing	0.002T –0 0015L	0.003L
Bushing in sun gear	0.0015T–0 003T	0.000L
Ball rings on barrel	0.001L –0 003L	0.010L
Spline nut bushing on spline nut	0.001L –0 004L	0.010L
Sun gear thrust washer:		
Small (thickness) in.	0.060 –0.064	0.030 min.
Large (thickness) in.	0.062 –0.066	0.030 min.
Sun gear on barrel shaft	0.0005L–0.0015L	0.010L
Pump driving gear on intermediate gear shaft	0.0005T–0.0010L	1/64 in. rotation at circumference of gear
Clutch driving gear ball bearings:		
In housing	0.0006T–0.0002L	0.002L
On gear	0.0001T–0.0006L	0.002L
Ball bearing in pump housing	0.0003T–0.0001L	0.0001L
Pump shaft in ball bearing	0.000T –0.0005T	0.0000L
Rotor keys:		
In shaft	0.001T –0.001L	0.001L
In inner rotor	0.0005L–0.0025L	0.0025L
Inner rotor on shaft	0.0000T–0.0004L	0.0004L
Outer rotor in eccentric ring	0.0031L–0.0039L	0.0039L
Eccentric ring in housing	0.0001T–0.0004L	0.0004L
Eccentric ring, thickness	0.8332 –0.8333	†
Outer and inner rotor, end play	0.0030 –0.0033	0.0030–0.0033
Face plate, thickness	0.150 –0.156	†
Port plate, thickness	0.150 –0.156	†

* The letters L and T mean "loose" and "tight" by the amount shown.

† Minimum total thickness of eccentric ring, port plate, and face plate is governed by the clearance between the pump body and head which must not be less than 0.0015 in.

Similar tolerances are given in Table 2, for types 405 and 634 of the direct cranking electric starters with feathering pumps, used in connection with Hamilton standard propellers to facilitate the inspection of parts for wear and to check clearances when reassembling starter pumps at overhaul.

Test at Disassembly.—Test the armature and yoke and field coil assembly for shorted, grounded, and open circuits before assembling with a 220-volt a.c. or d.c. line having a lamp in series. If a 220-volt line is not available, a 110-volt line will suffice.

Figure 9 shows the construction of both type I and II cartridge starter. A study of the two sectional views will show the piston, the inner and outer screws, and the balls. The numbered parts are also referred to in Table 3, which follows. This list will show when parts need to be replaced.

Table 3.—Tolerance Chart—Eclipse Cartridge Starter

No.	Parts fit	New fit	Serviceable limit
1	Length of flat on leading edge of starter jaw teeth, in.	7/32	3/16
2	Replace baffle plate assembly if oil seal leather is worn or damaged to the extent that an improper oil seal is maintained.		
3	Starter jaw on screw shaft—backlash between splines	0.003L	0.030L
4	Replace meshing rod spring if free length is less than 1 1/16 in. or if force required to compress spring to a length of 27/32 is less than 52 lb.		
5	Thrust sleeve on intermediate head	0.001L –0.004L	0.015L
6	Thrust bearing O.D.:		
	Type I	0.001L –0.0026L	0.004L
	Type II	0.0005L–0.002L	0.004L
7	Thrust bearing I.D.:		
	Type I	0.0004L–0.002L	0.004L
	Type II	0.0009L–0.0029L	0.004L
8	Replace meshing sleeve and spring assembly if force required to compress detent balls flush with outside diameter of meshing sleeve is less than 11 lb.		
9	Replace intermediate head, screw shaft, or threaded sleeve if ball grooves are excessively pitted.		
10	Replace valve rod spring if force required to compress spring to a length of 1/2 in. is less than 4 1/2 lb.		
11	Replace piston return spring of type I starter if free length is less than 9 3/4 in. or if force required to compress spring to 6 7/8 in. and 3 in. is less than 80 and 100 lb. respectively.		
12	Replace piston return spring of type II starter if free length is less than 9 1/8 in., or if force required to compress spring to 6 7/8 in. and 3 in. is less than 125 and 325 lb., respectively.		
13	When asbestos packing rings are worn or damaged to the extent that they will no longer maintain a proper seal, they must be replaced.		
14	Piston ring end clearance:		
	In cylinder	0.015L–0.020L	0.030L
	Free, in.	3/8	1 1/32
15	Replace intake housing gasket if damaged. Vary gasket thickness to obtain required position of inlet and exhaust posts.		
16	Replace valve snap lock if force required to seat valve over the snap lock is less than 14 lb.		
17	Replace valve rod and plate assembly if scored or pitted to the extent that leakage occurs.		

SECTION XIV

PROPELLERS

Propellers with a fixed pitch, or solid, are now used only on small private planes and for training planes. These are the only fields for the wooden propeller, metal being used almost exclusively on transport and military planes. The adjustable, or variable pitch, propellers have many advantages as will be shown; but they involve the use of considerable mechanism which requires great care both in the making and in the maintenance. Details of some of the propellers follow.

HAMILTON PROPELLERS

Variable Pitch Propellers.—The variable pitch propeller has several advantages. It permits the use of the most efficient pitch angle at all times. With the fixed propeller, the Department of Commerce and airplane engine builders require the setting of the pitch so that the engine turns at its rated r.p.m. with full throttle at level flight. Although this is necessary to prevent abuse of the engine, it means that the power is held down to about 80 per cent of normal when the plane is taking off. Even the two-position controlled propeller largely avoids this loss, although the constant-speed control permits maximum power at all times. With the two-position controller the low pitch is adjusted for engine power during take-off and climb and the high pitch gives the desired engine speed at level flight. With the constant-speed propeller the manual control gives the pilot a choice of engine speeds. The pitch of the propeller is changed automatically so as to maintain any r.p.m. he selects. The advantage of this is shown in Fig. 1.

Hamilton Standard Propeller.—The second type is the automatically controlled propeller. The Hamilton Standard propeller is controlled by hydraulic pressure, its mechanism having been developed over a long period to its present construction. Oil pressure moves the blades toward the low-pitch position. They are moved to the high-pitch position by centrifugal action of counterweights attached to the blade brackets. Details are shown later.

Constant-speed control is secured by a device used in conjunction with the hydro-controlled propeller already mentioned. This control permits the independent setting of engine power and speed at any time, both of which will be maintained during all normal flight conditions or until the pilot readjusts the controls.

The constant-speed control is a self-contained governor bolted to a pad on the engine nose; it is geared to the engine in such a way that its operating range coincides with the r.p.m. range of the engine. A small booster pump takes oil from the engine lubricating system and increases the pressure to 180 to 200 lb. This pressure is regulated by a relief valve through which oil not needed to shift the propeller returns to the inlet side of the pump. Governing action is secured by a flyball working against a spring. The balance between these two forces controls the metering of the oil to and from the propeller cylinder.

Quick-feathering Propellers.—A third type of Hamilton Standard propeller is known as the hydromatic "quick feathering." Many of the principles are similar to the counterweight type, constant-speed propellers. In addition, however, these propellers have a full-feathering feature by which the blades can be turned to such a high pitch as to stop engine rotation

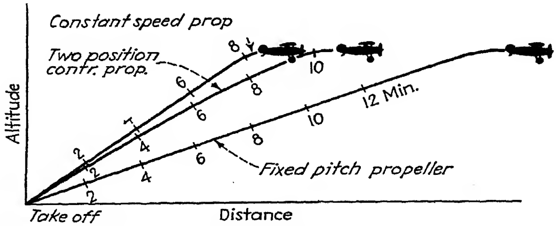


Fig. 1.—Diagram showing how a constant-speed propeller gains altitude in a minimum amount of time.

and reduce propeller drag to a minimum. Having the blades in the direction of flight greatly improves the performance of the other engines in a multi-motored plane and it also prevents accidents resulting from broken or unbalanced parts which cause excessive vibration or even tear the engine loose.

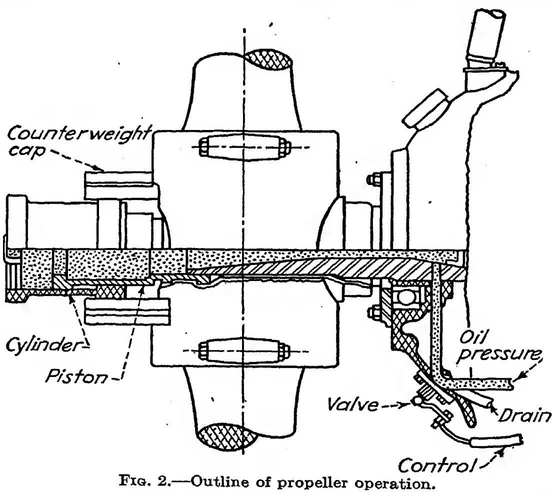


Fig. 2.—Outline of propeller operation.

Blades can be "unfeathered" and the engine started by the "windmilling" of the propeller, after repairs have been made or when it is deemed advisable to do so.

Principle of Operation.—The Hamilton Standard controllable propeller utilizes the hydraulic principle of operation. It gives a positive means of

control with a minimum number of parts; light weight with simplicity of construction; high dependability with long life. The control forces are carefully calculated to be ample for the purpose.

The oil pressure is obtained from the engine, and the flow of this oil is controlled by a manually operated valve. In one position the valve allows the oil to flow from the engine through the transfer rings into the front end of the engine shaft and out to the propeller cylinder. In the other position it shuts off the flow from the engine and allows the oil in the propeller cylinder to drain back to the engine sump. An outline is given in Figs. 2 and 3.

Since it is the oil in the propeller cylinder that holds the blades in low pitch and prevents the pull of the centrifugal force on the counterweights from rotating them to high pitch, it is apparent that they will move toward high pitch as soon as the oil is released. The hydraulic and centrifugal operating forces are such that when the revolutions are below normal, extra force is available for movement toward low pitch. When the revolutions are above normal, extra force is available for movement toward high pitch.

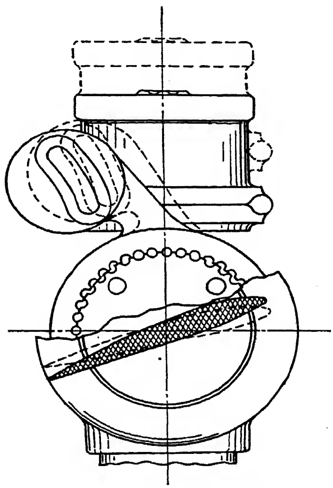


Fig. 3.—The high-pitch position is shown by solid lines; the low-pitch position by dotted lines.

Modern high-powered American engines have a built-in valve as standard equipment. Adaptations for other engines have been worked out in cooperation with the manufacturers. If it is desired to install a controllable propeller on an engine without the valve, the engine manufacturer should be consulted.

With the constant-speed propeller, the control valve is replaced by a unit called the "constant-speed control." In this case the flow of oil is exactly the same, except that the constant-speed control automatically regulates the amount of oil that enters or drains from the cylinder of the propeller.

Description of Parts.—The *spider* is a chrome-nickel-molybdenum steel forging. Its splines, cone seats, and arms are machined to close tolerances. It connects the propeller to the engine and carries the torque and thrust loads on the blades. Figure 4 shows its various parts.

The *barrel* is a chrome-vanadium steel forging. Its primary function is to carry the centrifugal load of the blades. It is held on the spider by *micarta barrel supports* located between the spider arms.

Oilite *shim plates* protect the spider from galling. Their outside diameter is small enough to prevent them from contacting the barrel, and they are free to turn on the spider shoulders. To ensure a reasonably tight fit of the blade assembly parts which are held between the spider and the barrel, *laminated shims* are peeled to the required thickness and placed between the shim plates and the spider.

Leather *grease retainers* fit in the fillet at the base of each spider arm, and prevent grease from being thrown from the blade bushings and spider arms. One side of the retainers is beveled to fit the fillet.

The *piston* is machined from a bar of chrome-vanadium steel. It acts as the retaining nut to hold the propeller on the engine shaft, and also as the guide for the cylinder. Its base is threaded to fit the end of the engine shaft. Its outer end has a shoulder machined to carry the *piston gaskets.* The outboard piston gasket forms an oil-tight seal between the cylinder and the piston. The inboard gasket is merely a sleeve to permit the piston to guide the cylinder without metal-to-metal contact.

The *cylinder* is an aluminum alloy forging. It is arranged to slide back and forth on the piston and in so doing to impart a rotating motion to the

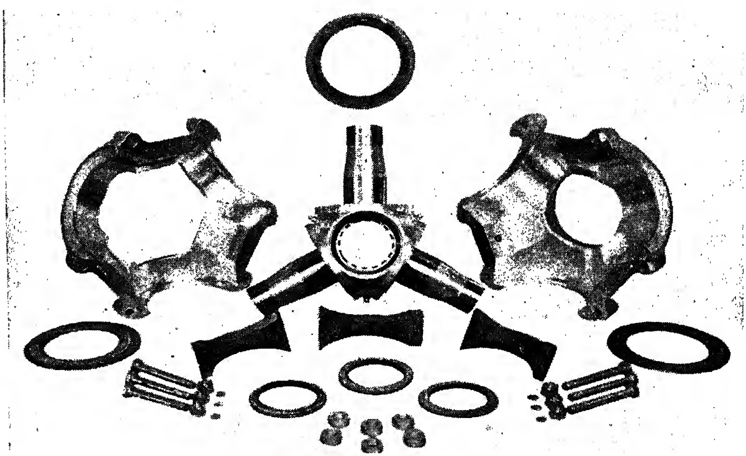


Fig. 4.—Parts of a three-blade propeller hub.

blades by means of the counterweight brackets. Oil pressure fed through the engine shaft into the piston forces the cylinder outward. This rotates the blades toward low pitch. Centrifugal force on the counterweights acts against this motion so that when the oil pressure is released the cylinder is moved inward allowing the counterweights to turn the blades toward high pitch. A steel liner is provided in the large bore of the cylinder to prevent wear due to sliding on the piston gaskets. A micarta liner in the small bore at the base of the cylinder eliminates galling and chafing between the cylinder and piston. Threaded holes are provided in the flanged base of the cylinder for installation of the counterweight bearing shafts. In the smallest size of propellers there is a bronze bushing in each of these holes to act as a bearing surface for the counterweight brackets to slide along as the propeller changes pitch. Larger sizes have ball bearings, called *cylinder bearing shaft thrust bearings,* which provide rolling contact between the counterweight brackets and the cylinder.

The *counterweight bearing shaft* is of chrome-vanadium steel, with one end threaded to fit the cylinder holes mentioned. The other end consists of a spherical segment, which fits the ball seat in the counterweight bearing cap race, and a short extension of the shaft proper. The end of this short extension has a socket for a $\frac{3}{16}$-in. Allen wrench which is used to tighten the shaft in the cylinder. After it is tightened in place, each shaft is locked with a clevis pin and cotter (see Figs. 5 and 6).

The *counterweight bearing* consists of a curved steel race, a curved bearing retainer, and a circular steel cap race. The curved (inner) race fits snugly in the cam of the counterweight bracket. The circular cap race has a ball seat on its outer side in which the spherical segment of the bearing shaft fits. The retainer is held in place between the two races by means of the bearing shaft. A *spacer* that serves as a guide for the retainer is also included in all except the small sizes. This spacer maintains the correct alignment of the retainer while changing pitch (see Fig. 5).

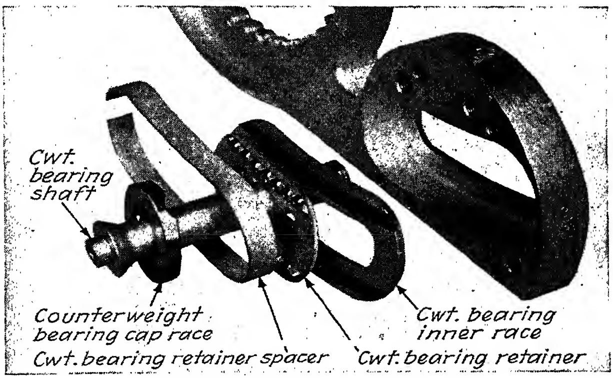


Fig. 5.—Counterweight parts and connections.

The *counterweight bracket* is a chrome-nickel steel forging. The outer end contains the cam slot in which the counterweight bearing moves. The other end fits around the blade bushing. The portion of the bracket next to the blade bushing is scalloped with 40 semicircular holes. Four of them can be matched with four of the 36 semicircles that compose the base circumference of the blade bushing. Index pins, tapped into the four aligned sets of semicircles, lock the parts together.

A steel *counterweight* is fastened to the outer face of the bracket by fillister screws. A slot in the counterweight corresponds to the cam in the bracket. A short extension of the bearing shaft moves up and down this slot. Along one side of this slot is a scale of degree graduations. These are stamped during final assembly and correspond with protractor measurements of the blade angle at the 42-in. station. Toward one end of the slot is a lead insert on which is stamped the base setting of the blade.

The *adjusting screw*, with its nuts, fits in the slot in the counterweight and is held from turning by a pin. The nuts may be turned up or down the screw, independently of each other, to any desired position indicated on the

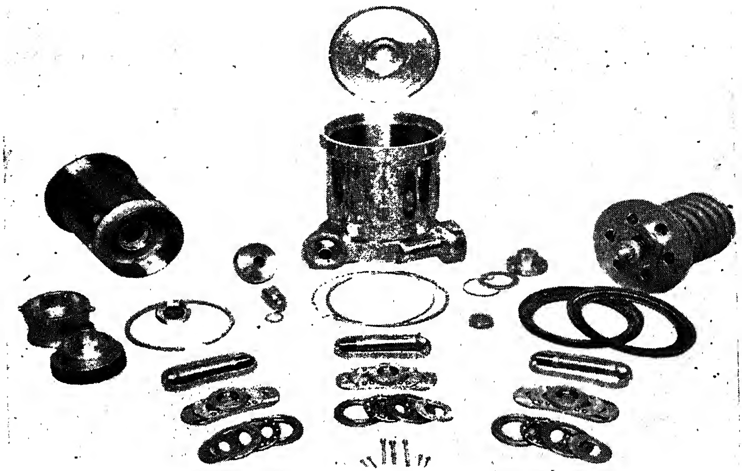


FIG. 6.—Parts of counterweight mechanism.

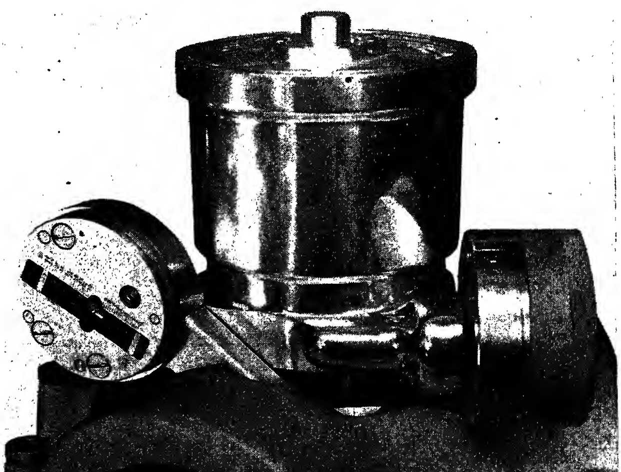


FIG. 7.—Two of the assembled counterweights. The one at the left shows the adjusting screw.

stamped scale. As the bearing shaft moves in the cam, its extended end contacts these nuts, thus limiting the pitch setting of the blades (see Fig. 7).

A *counterweight cap* screws on the face of the counterweight. It acts both as a protecting cover for the adjusting screw and as an added weight whose centrifugal force helps pull the blades into high pitch.

The *blade* is an aluminum alloy forging, machined and ground to shape, then polished. The blade tip is solid permitting thin sections and accurate forming which lead to very high aerodynamic efficiency. The blade shank is hollow with rugged walls. This semihollow construction makes it possible almost to double the bending strength of the inner portion of the blade without excessive increase in weight. The taper bore of the hollow blade shank with its bushing, together with the form of the outside of the blade, provides almost complete freedom from any tendency toward localization of stresses that might cause blade breakage at the shank.

The *thrust bearing assembly* consists of two thrust rings, which cannot be removed from the blade, and a split thrust bearing retainer. These roller thrust bearings are designed for high capacity and permit the blades to rotate with minimum friction. The design of the roller bearing races makes possible the use of extremely large fillets, with the resulting increase in resistance to fatigue. This method of blade attachment is estimated to be at least three or four times as strong as the usual type of retaining shoulder having moderate size fillets. The type of roller thrust bearing used has the highest known load capacity per square inch of roller surface. The location of the roller bearing around the outside of the blade, in conjunction with the centering action of the spider on the inside of the blade, permits a large roller area without excessive weight.

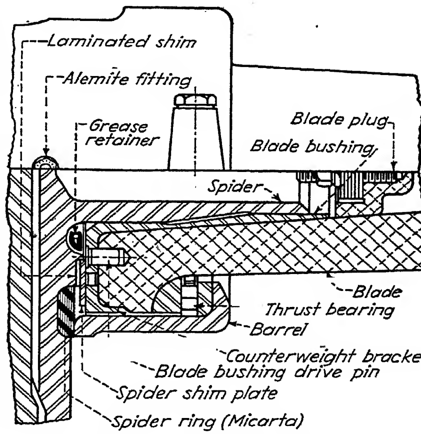


FIG. 8.—Assembly of bushing on shank of blade and in barrel.

A *blade bushing*, made of aluminum-iron-bronze, is pressed tightly into the hollow end of each blade shank. It is held in place by two drive pins and two lock screws. Care is taken to assure the correct alignment between the inside of the bushing and the blade face, as well as the correct relation between the semicircles on the circumference of the bushing and the blade pitch (see Fig. 8).

An aluminum *blade plug* is pressed into the hollow shank, just beyond the end of the blade bushing, to prevent lubricant from filling the small end of the tapered bore. In addition it is provided with a stud on which washers are installed as a means of balancing. The stud will hold a total of 10 thick washers or 20 thin ones. Factory specifications on new blades require at

least one thick washer and no more than five thin ones so as to permit adjustment in the field.

Model Designation.—A system of model designation has been adopted which is intended to simplify the designation of propeller assemblies. For the explanation of this method the 2D30-1 model propeller will be taken. In this case the "2" indicates that the propeller has two blades; the "D" is the blade shank size; the "30" is the S.A.E. shaft size; the dash number indicates that the propeller is for right-hand operation. Right-hand propellers, viewed from the cockpit of tractor-type airplanes, or from the propeller's slipstream on pusher-type airplanes, have *odd* dash numbers; corresponding left-hand propellers have the succeeding *even* numbers. Any major changes that may be incorporated in the basic design are identified by numbers prefixed to the original designation, such as 12D30-1 for the first change, 22D30-1 for the second change, and so on. Minor changes are indicated by adding to the dash number, such as 12D30-11 or 12D30-12.

Installation, Assembly, and Disassembly

Hamilton Standard propellers may be divided into the following groups:

20-deg. Propellers (with springs)
  3E50
  2E40, 3D40
E and D Shank Propellers (without springs)
  3E50, 2E40, 3D40
  12D40, 2D30
B Shank Propellers

The three-way propellers are usually shipped with the blades disassembled from the hubs; the two-way propellers are usually shipped assembled.

Hamilton Standard 20-degree Propellers (with Springs).—*Note:* These propellers can be used only in combination with Hamilton Standard constant-speed controls.

With the development of the constant-speed control it became advantageous, for certain types of airplanes, to have a propeller whose blade pitch could move over a wide range. The 20-deg. propeller was developed to meet this requirement.

This propeller uses the same hydraulic principle of operation as the two-position controllable propeller, except that the action of a spring return assembly is added. This assembly is installed inside the propeller piston. It is compressed when the propeller shifts to low pitch, thus aiding the operating force of the counterweights in returning the propeller to high pitch. The spring force is greatest in full low pitch, becoming less and less as the pitch shifts toward high. About two-thirds of the way from full low pitch to full high pitch the spring force is discontinued, and the counterweights alone provide the operating force.

It is because of the increased angular travel of the counterweights and the slope of the counterweight cams that the spring return is needed with 20-deg. propellers. In them the usual engine oil pressure is not enough to shift the blades to low pitch. A booster pump, incorporated in the Hamilton Standard constant-speed control, is used.

The three propellers in this group have pistons designed to use the stand ard split front cones furnished by the engine manufacturer. These cones do not come with the propeller.

The pistons are for installation on engines with standard No. 50 and No. 40 S.A.E. spline shafts. Oil enters the piston through an engine-shaft oil plug.

By using different types of oil plugs it is possible to have one piston design for all engines whether the crankcase ventilation is through the crankshaft or otherwise.

To Install the 3E50 20-deg. Propeller.—1. Remove the screw plug from the propeller oil feed line inside the crankshaft.

2. Install the correct engine shaft oil plug or oil supply pipe.

3. Dress off all corrosion, galling, scores, and scratches on the crankshaft and install the bronze rear cone on the engine shaft, against the thrust nut.

4. Install the split front cone on the propeller piston. It is recommended that the cylinder and piston be removed from the propeller for this installation. This is because the front cone cannot be installed without moving the cylinder out toward low pitch. Also any movement of the cylinder, before the piston is screwed on the crankshaft, tends to cock the assembly, which makes it difficult to start the piston on the crankshaft and may cause the damaging of the crankshaft threads.

The cylinder and piston are removed by unscrewing the counterweight caps, taking the adjusting screws out of the cams in the counterweights, removing the counterweights, and unscrewing the counterweight bearing shafts. Be careful, in removing the adjusting screws, not to disturb the position of the nuts.

5. Oil the crankshaft and the rear cone.

6. Put the propeller on the crankshaft.

7. Oil the front cone and the piston threads.

8. Assemble the cylinder, piston, snap ring, and front cone. When placing this assembly on the crankshaft, be sure that the numbers above the cylinder bearing shaft bushings correspond to the adjacent counterweight brackets.

9. Screw the piston on the crankshaft. Make sure that the piston and crankshaft threads are in perfect alignment. In no case should force be used to tighten the piston if there is binding or indication that the threads are not properly started. As the piston is turned on the crankshaft, the oil supply pipe in the engine shaft is forced through the gasket at the base of the piston.

10. Tighten the piston on the crankshaft. Use the propeller wrench and a bar about 4 ft. long. Apply a force of approximately 180 lb. at the end of the bar. To ensure the piston's being pulled home, the bar should be rapped once on the section next to the wrench. Use a normal swing with not more than a 2½-lb. hammer. This should be done while the force is being exerted at the end of the bar. This operation should be repeated after the first flight and a check made at the end of 25 to 50 hr. to see that the piston is tight.

Caution. Do not attempt to tighten the piston by hammering on the *end* of the bar.

11. Snap the snap ring in place.

12. Install the two piston gaskets; the one having the longer flange is the inboard gasket.

13. Install the counterweight bearing shaft thrust bearing assemblies in the cups of the cylinder bearing shaft bushings. This assembly consists of two circular races and a ball thrust retainer. The race with the smaller inside diameter is the inner race and should be installed in the cup first.

14. Place the counterweight bearing races, retainers, and cap races in the brackets. Slip the circular oilite washers between the outer race of the cylinder bearing shaft thrust bearing assemblies and the arm of the brackets.

Screw the bearing shafts in their correspondingly numbered holes. It is essential that the grooves in the counterweight races and the bearings in the counterweight retainer match. The curvature of this bearing is gradual. To make sure that the cap races are not assembled upside down, an arc is stamped on the outer face, indicating the direction of the bend in the grooves. After the bearing shaft has been screwed up tight, this arc should be checked.

15. Lock the bearing shafts in the cylinder with the bearing shaft clevis pins, and cotter the pins.

16. Slip the spacers into place in the counterweight bracket slots and assemble the counterweights, making sure that the number of each corresponds to its bracket.

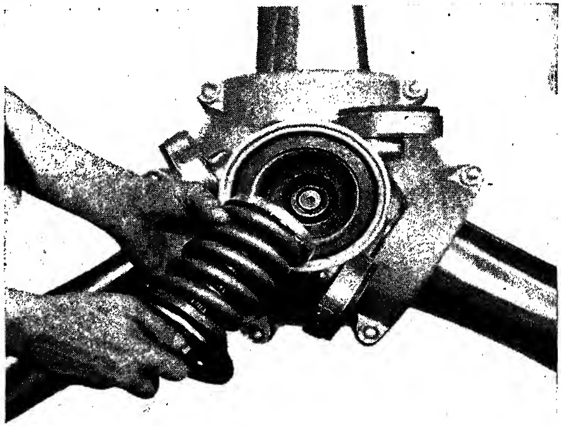


Fig. 9.—Inserting a coil spring in a propeller hub.

17. Insert the complete spring assembly in the piston and tighten the piston gasket nut (see Fig. 9). Use a bar approximately 2 ft. long.

18. Place the cylinder head gasket on the cylinder head. A light coating of grease will hold this gasket in place.

19. Screw the cylinder head on the cylinder. This should be tightened with the bar used on the piston gasket nut. As the cylinder head is tightened, the clamp washer on the splined spring puller bolt will enter the guide on the underside of the cylinder head. The purpose of this guide is to help center the puller bolt.

20. Lock the cylinder head with its lock ring.

21. Lock the cylinder head to the spring puller bolt by means of the vernier lock plate. By turning the vernier one cog at a time, a combination will be found that will allow the vernier to be pushed in place. The groove and ring on one side of the vernier are to facilitate its removal and should be towards the front (see Fig. 10).

22. Put a clamp nut gasket in place on the cylinder head.

23. Tighten the clamp nut on the threaded end of the spring puller bolt. A relatively short wrench should be used. The object is merely to hold

the clamp washer on the spring puller bolt tightly against the cylinder head, and provide an oil seal.

24. Lock the clamp nut with its lock wire.

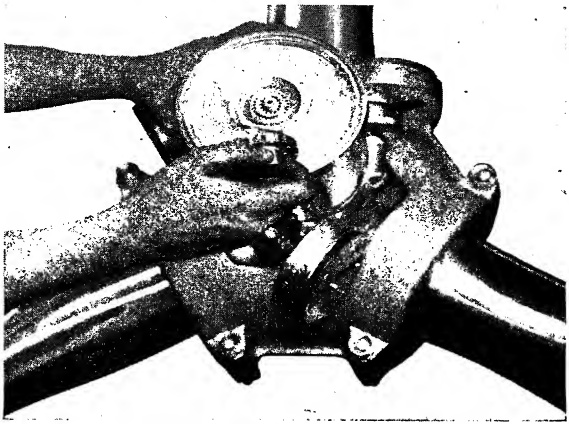


FIG. 10.—Putting the vernier lock plate in place.

25. Place the adjusting screws in the counterweights. Be careful not to disturb the adjusting nuts. The cylinder may be moved approximately

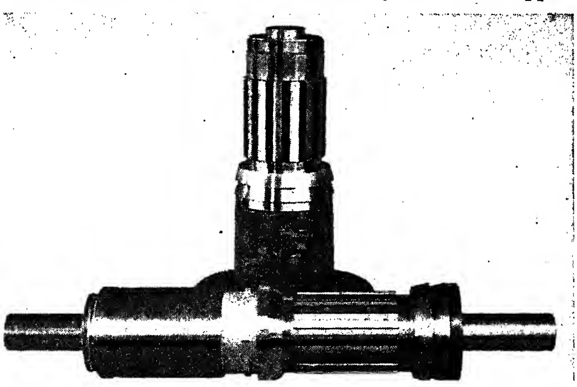


FIG. 11.—S.A.E. 50 splined bushing and mandrel assembly.

8 deg. from the basic index setting before the springs become effective. If the high-pitch setting is more than 3 deg. from the base setting, the propeller should be reindexed.

26. Screw on the counterweight caps, making sure that the number on each corresponds with its bracket.

27. Put in the counterweight cap clevis pins and cotters.

28. Check all lock wires and cotters.

Assembly.—To obtain the correct blade angle settings and balance, it is essential that the propeller spider be accurately located and firmly held on a bushing. Use a splined bushing whose measurements are identical to those of the engine crankshaft. This bushing is inserted in the spider. When a piston, with split front cone, is tightened onto the bushing, the front and the rear cone are firmly seated on the ground tapers of the spider.

The splined bushing has a centering hole which fits either the spindle of the checking table or the mandrel used for balancing (Fig. 11). This combination of piston, split front cone, spider, splined bushing, rear cone, and

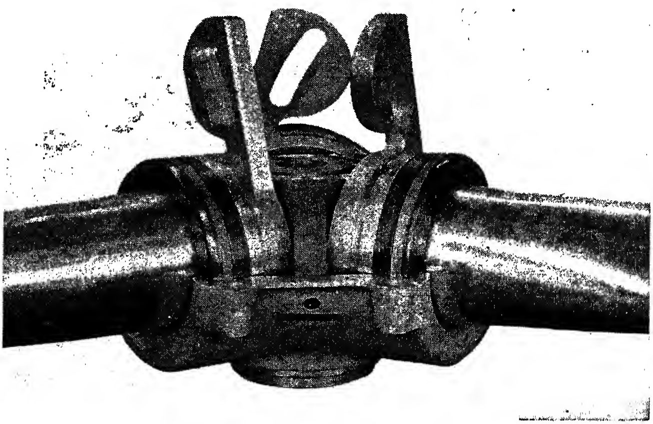


Fig. 12.—Thrust bearing retainers between the thrust races.

spindle (or mandrel) ensures the elimination of any play, thus allowing accurate blade settings and balance to be obtained.

1. Place the splined bushing (S.A.E. 50) on the spindle of the checking table.

2. Place the rear half of the barrel over the spindle and splined bushing.

3. Slide the spider down on the splined bushing.

4. Coat the spider arms with grease.

5. Place the laminated shims on the shoulder at the face of the spider arms.

6. Place the oilite shim plates on the spider arms against the laminated shims.

7. Place the leather grease retainers in the fillet at the base of the spider arms. One face of the grease retainer is turned to fit this fillet.

8. *Wrap the blade shanks with cloth to prevent the steel thrust races from marring or injuring them.*

9. Assemble the blade brackets on their correspondingly numbered blades. For the proper relationship of the bracket and blade bushing, see page 447. Be sure that four index pins are used for each blade.

If the propeller has just been received from the factory, fill the blade bushings with grease to within 2 in. of the top. If the propeller is being assembled after an overhaul and its balance must be checked, leave the blade bushings dry.

10. Install the three micarta barrel supports.

11. Remove the Alemite fittings from the spider and shove the blades on their correspondingly numbered spider arms. If the propeller has just been received from the factory and the blade bushings have been filled with grease, the excess grease will be forced through the open Alemite fitting holes. It is recommended that three extensions, made from ⅛-in. pipe and threaded on one end, be used to lead this excess grease through the micarta barrel supports.

12. Screw in the Alemite fittings.

13. Cover the blade thrust bearing races and retainers with a thin coating of Mobilgrease No. 2, or its equivalent.

14. Place the thrust bearing retainers in position between the thrust races (Fig. 12).

15. Align the etched "O" on the inner thrust race with the stamped "O" on the blade shoulder (Fig. 13).

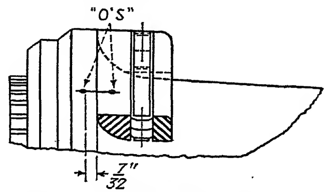


Fig. 13.—Aligning inner thrust race and blade shoulder.

16. Lift the lower half of the barrel up on the spider blade assembly so that it starts evenly on all three outer thrust races. Make sure that the numbers on each arm of the barrel correspond with the blade numbers on which they are fitting.

17. Tap the lower half of the barrel up into place on the assembly.

18. Place the front half of the barrel over the counterweight brackets and tap down in place. Make sure that the numbers on each arm match the corresponding blade numbers. It will be necessary to rotate the brackets in order to fit the front half of the barrel in place. Care must be taken to keep the brackets clear of the barrel as it is tapped home.

19. Install and tighten the barrel bolts in their respectively numbered holes. Use a wrench having not more than 14-in. leverage. Excessive tightening of the nuts may cause failure of the barrel bolts.

At this point check the tightness of the fit of the blades in the hub assembly. This can be done by measuring the amount of torque necessary to turn each blade. (If a propeller has just been received from the factory and is being assembled for the first time this measurement is not necessary.)

Using a lever arm clamped to the blade and a set of spring scales attached to the other end of the lever arm, apply sufficient pull on the scales to turn the blade. This pull (in pounds) multiplied by the distance (in feet) from the point of application to the center line of the blade is the torque (in pound-feet). It should be no greater than 90 and no less than 50 lb-ft.

If it is found that the torque on one or more blades is not within this range, the propeller must be disassembled, and suitable corrections made by peeling the laminated shim, if the blade fit is too tight, or putting in a thicker laminated shim, if the fit is too loose. *Never reduce the thickness of the oilite shim plate to obtain the correct torque.*

20. Assemble the cylinder and the split front cone with a "dummy" piston, and put in place on the hub assembly. Be sure that the numbers on the cylinder arms correspond with the bracket numbers.

The regular piston has a small hole at its base for the oil supply pipe. This hole is too small to permit the spindle or the mandrel to pass through. It is necessary to replace the regular piston with a "dummy." This may be another piston in which the base has been cut out sufficiently to allow the mandrel to pass through.

21. Tighten the "dummy" on the splined bushing.

22. Place the cylinder bearing shaft thrust bearing assemblies in the cup-shaped counterweight bearing shaft bushings. The race with the smaller inside diameter is the inner race and should be put in the cup-shaped bushing first.

23. Install the counterweight bearing races and retainers.

24. Slip the oilite thrust washers between the outer races of the cylinder bearing shaft thrust bearing assemblies and the brackets and tighten the counterweight bearing shafts in place. Be sure that the numbers of these shafts correspond with the numbers on the cylinder arms.

25. Place the inboard (long-flanged) and outboard (short-flanged) piston gaskets on the piston and secure them in place with the dummy's piston gasket nut.

26. Fasten the counterweights on their respectively numbered brackets.

27. Install the adjusting screws in the counterweight slots.

28. Screw on the correspondingly numbered counterweight caps.

The propeller is now ready to have its angles checked which should be done and then dry balanced. See Balancing, and Blade Angle Adjustments, pages 450 and 451. The full high- and full low-pitch angles should always be checked to make sure that the brackets have been indexed correctly on the blade bushings.

29. Fill the propeller blade bushings with grease. It is recommended that this be done by disassembling the propeller, taking the blades off the spider arms and filling them to within 2 in. of the top with Mobilgrease No. 2 or its equivalent. This procedure is recommended because it eliminates the possibility of air pockets forming in the blade bushings and spider arms.

30. Reassemble the propeller (page 440).

Note: The regular 20-deg. piston (with snap ring and split front cone) may be assembled in the propeller in place of the "dummy" piston provided the splined bushing is shimmed up high enough to prevent the spindle of the table fixture (Fig. 11) from contacting the base of the piston when the piston is tightened on the splined bushing.

31. Install the inboard (wide-flange) piston gasket. The propeller is now ready to be placed on an engine crankshaft. This is done by following the steps listed under Installation with the exception of numbers 4, 7, 8, and 13 through 16. (These steps have been taken care of during assembly. If, however, any difficulty is encountered in starting the piston on the crankshaft threads, the counterweight bearing shafts should be removed and the installation made in accordance with steps 1 through 28 under Installation.)

32. Shift the blade angles by moving the cylinder up and down. This will align the piston-cylinder assembly.

Removal from Crankshaft.

1. Move the blades toward the full high-pitch position until the pitch is within 8 deg. of the basic index setting of the propeller. This is done to remove all compression from the springs.

Be sure that the blades are not more than 8 deg. away from the base setting or else the springs will be under compression and the threads of the clamp nut may be stripped when it is unscrewed.

2. Remove the clamp nut lock ring and unscrew the clamp nut.
3. Remove the vernier lock plate and the clamp nut gasket. *Failure to remove the vernier lock plate before attempting to unscrew the cylinder head will result in serious damage to the puller bolt.*
4. Remove the cylinder head lock ring and unscrew the cylinder head.
5. Unscrew the piston gasket nut and take out the spring assembly.
6. Remove the two piston gaskets.
7. Unscrew the piston.
8. Remove the propeller from the crankshaft. Take care not to damage the engine shaft threads.

Now that the front cone has been installed in the propeller and the propeller has been flown, the action of changing pitch has aligned the cylinder and piston. The propeller may be replaced on a crankshaft, without disassembling the counterweight bearings. *Care must be taken, however, not to jar the cylinder and piston out of alignment.* If there is any chance that the cylinder and piston have been shifted, the counterweight bearings should be disassembled to permit correct alignment of the piston threads on the threads of the engine shaft and thus ensure against damaging the shaft threads.

Disassembly.—To disassemble the propeller completely after its removal from the engine crankshaft:

1. Remove the counterweight cap clevis pins and unscrew the counterweight caps.
2. Record the position of the adjusting nuts with relation to the scale stamped on the counterweight face.
3. Remove the adjusting screws.
4. Take off the counterweights.
5. Remove the counterweight bearing shaft clevis pins.
6. Unscrew the counterweight bearing shafts and remove the counterweight bearing assemblies with spacers. Take care that the oilite thrust washers do not fall.
7. Disengage the snap ring from the spider groove.
8. Lift the piston-cylinder assembly. *Care should be taken that the cylinder bearing shaft thrust bearing assemblies do not fall out of the cups of the counterweight bearing shaft bushings and that the split front cone does not slip off the piston.*
9. Remove the barrel bolts.
10. Split the parting of the front and rear halves of the barrel using a brass or aluminum wedge.
11. Drift off the front half of the barrel. Take care to keep the arms of the brackets turned so that they do not contact the barrel as it is drifted up.
12. Drift off the rear half of the barrel. *The thrust retainers will fall when the rear half of the barrel drops off unless they are held in place.*
13. Wrap the blade shanks with cloth to prevent the steel thrust races from marring or injuring them.
14. Remove the Alemite fittings and micarta barrel supports.
15. Pull off the blades.
16. Remove the oilite shim plates and laminated shims. Keep these in pairs and marked so that they may be reassembled on the proper spider arms providing the laminated shims do not need replacing.

17. Remove the micarta barrel supports.
18. Remove the leather grease retainers.
19. *Note and record the location of the brackets on the blade bushings.*
20. Remove the brackers from the blades. Take care that the index pins are not lost when the brackets are drifted off the blade bushings.

The propeller is now completely disassembled and ready to be cleaned, inspected, overhauled, and assembled.

A clearance chart is seen in Fig. 14. The two values at the left show high and low sizes. The figure at the right is the largest permissible clearance before replacement.

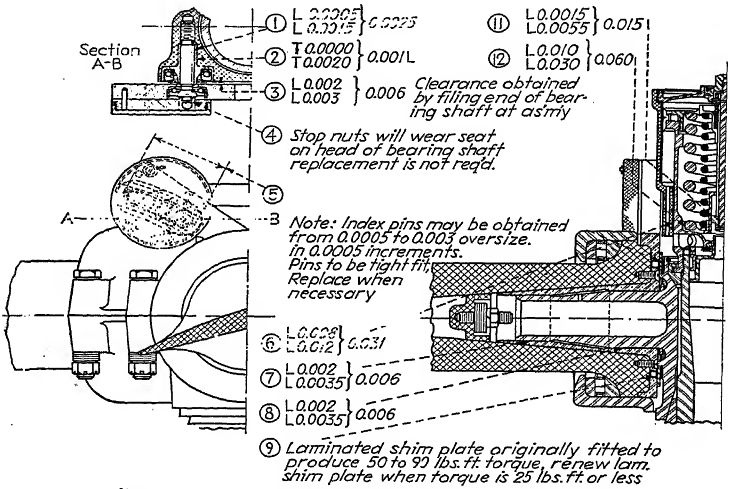


FIG. 14.—Chart showing clearances on the 20-deg. propeller.

"No. 1" means that the minimum clearance, or looseness, is 0.0005 in.; that 0.0015 in. is permissible when new, but that when wear increases the clearance to 0.0025 in., the parts should be replaced. "No. 2" can go from a tight fit of 0.002 to a clearance of 0.001 in. before replacement. These clearances are taken at 70°F.

The 2E40 and 3D40 20-deg. Propellers.—The 2E40 and 3D40 20-deg. propellers are the same as the 3E50 20-deg. propeller except for their size and the design of certain parts. The differences are as follows:

1. The cylinder of the 2E40 and 3D40 propellers is smaller in cross-sectional area than that of the 3E50.
2. The cylinder heads and the piston gasket nuts of the 2E40 and 3D40 deg. propellers are dome-shaped.
3. The cylinder bearing shaft thrust bearing assemblies are identical with those used in the 3E50 20 deg. but the designs of the cylinder arms and of the counterweight bearing shaft bushings are different.
4. The 2E40 is equipped with a micarta ring that fits in the groove on the rear of the spider.

The installation, assembly, removal from crankshaft and disassembly are the same as for propeller 3E50, 20 deg., pages 437 to 444.

Hamilton Standard E and D Shank Propellers (without Springs): *The 3E50 (10 deg.), 2E40 (10 deg.), 3D40 (10 and* 15 deg.).—In appearance, these propellers are similar to the corresponding 20-deg. propellers. Springs are not used because the slope of the counterweight cams is not so great as for the 20-deg. propellers.

The pistons are the same as those in the corresponding 20-deg. propellers. With the use of the correct oil plug or supply pipe assembly, these propellers are interchangeable between Pratt and Whitney and Wright engines.

The locking arrangement is the same as that used on the 20-deg. propellers, namely, a splined bolt in combination with a vernier lock plate.

Because no springs are used, there is no pulling force exerted on the splined bolt. This removes the danger of stripping the threads of the clamp nut when removing the propellers from the engine crankshaft. It is recommended, however, that the propeller always be in, or near, full high pitch before its removal from the crankshaft. This recommendation is made for two reasons: (1) In this position, the cylinder is not full of oil. (2) The propeller must be near full high in order to use the wrench for unscrewing the piston.

The installation, assembly, removal from crankshaft, and disassembly are the same as for the 3E50 20-deg. propeller, except that reference to springs does not apply. The clearances are the same as in Fig. 14.

The 12D40 (10 and 15 deg.) and 2D30 (10 and 15 deg.).—These propellers do not have springs. They are locked to the engine shaft by lock rings instead of the vernier lock plates. The method of feeding oil into the cylinders makes use of two different types of pistons as follows. For Pratt and Whitney engines the piston provides direct passage for the oil from the engine shaft to the propeller cylinder. For Wright engines the piston has several holes at its base to permit crankcase ventilation and the oil is fed through a supply pipe to the piston gasket nut. A packing in the piston gasket nut prevents leakage. In the Pratt and Whitney type this oil seal is taken care of by a washer that fits in a groove in the split front cone, which is furnished with the propeller.

Installation.—1. Inspect and clean the cone seat, engine shaft, and rear cone.

2. Clean out the inside of the crankshaft.
3. Remove the screw plug from inside the crankshaft.
   a. On Wright engines, screw the *oil supply pipe* in the oil plug hole which is located inside the crankshaft. (Some models require a gasket under the oil supply pipe.)

4. Locate the rear cone on the engine shaft against the thrust nut or spacer.

5. Remove the propeller cylinder head lock wire and unscrew the cylinder head.
   a. On propellers for Wright engines, remove the piston gasket nut, breather pipe packing nut, and packing. The piston gaskets will now be loose and should be removed in order to prevent damaging.
   b. The piston gaskets may be left in place on other engine installations.

6. Place the propeller on the crankshaft.. Make sure that the piston and crankshaft threads are in perfect alignment. In no case should force be used to tighten the piston if there is binding or indication that the threads

are not properly started, otherwise serious damage may result. Where it is found that, owing to handling or reassembly without proper adapters, the piston and shaft are not in alignment, the counterweights should be disassembled and the bearing shafts removed. This frees the cylinder and piston to permit easy starting of the threads and proper tightening of the propeller on the shaft. The counterweights may then be reassembled. Care should be taken in tightening the piston to see that the front cone packing washer, when one is required, does not bind but is pulled properly into place. (Wright engines do not require packing washers.) As an aid in assembly, it is suggested that the piston be tightened a few turns and then the hub jarred slightly by hand. This will help prevent jamming the washer on the shaft threads.

7. Tighten the piston using a bar approximately 4 ft. long. Apply a force at the end of the bar of about 180 lb. To ensure the piston's being pulled home, the bar should be rapped once on the section next to the wrench. Use a normal swing with not more than a 2½-pound hammer. This should be done while the force is being exerted at the end of the bar. This operation should be repeated after the first flight and a check made at the end of 25 to 50 hr. to see that the piston is tight.

Do not attempt to tighten the piston by hammering on the end of the bar.

8. Secure the piston with a lock ring. Cotter the lock ring using steel cotter pins (two or three as required).

9. On propellers for Wright engines, install the piston gasket nut and cotter.
   a. On other engine installations, check to see that piston gasket nut is cottered.
   b. On propellers for Wright engines, put the breather pipe packing and packing nut in place. Tighten the packing nut and secure it with locked wire.

10. Install the cylinder head and the cylinder head gasket, being sure that the gasket rests squarely on the cylinder head. The gasket may be held in place with grease.

11. Tighten the cylinder head.

12. Secure the cylinder head with its lock wire.

13. Check all cotters and lock wires.

Assembly.—1. Place the splined bushing (S.A.E. 30 or 40 according to the propeller) on the spindle of the checking table (Fig. 11).

2. Place the rear half of the barrel over the spindle and splined bushing.

3. Slide the spider down on the splined bushing.

4. Place the two halves of the micarta spider ring on the fillet at the base of the spider. The flats should be under the spider arms.

5. Coat the spider arms with grease.

6. Place the laminated shims over the shoulder at the face of the spider arms.

7. Place the oilite shim plates against the laminated shims.

8. Place the leather grease retainers in the fillet at the base of the spider arms. One face of the grease retainer is turned to fit this fillet.

The steel thrust races on the blades should be wrapped in cloth to prevent them from marring the blade shanks. Remove cloth just before placing the thrust bearing retainers in position.

9. Assemble the counterweight brackets on their correspondingly numbered blades (Fig. 15). Be sure that *four* index pins are used for each blade.

10. Install the micarta barrel supports.

11. Coat the spider arms with a film of grease, Mobilgrease No. 2 or its equivalent.

12. Shove the blades on the correspondingly numbered spider arms. To prevent air pressure from building up in the spider arms as the blades are shoved in place, the Alemite fittings may be removed or a wire used to open their check valves.

13. Grease the thrust bearing retainers and install them between the blade thrust races.

14. Check to be sure that the inner thrust race is assembled in the marked position. An O is etched on the race and stamped on the blade (see Fig. 13).

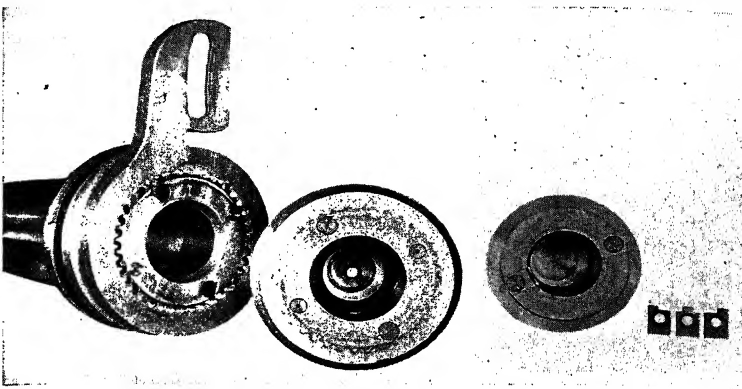


FIG. 15.—Assembling counterweight brackets on their proper blades.

15. Raise the rear half of the barrel and tap it up on to the assembly. See that the numbers on the arms correspond to the blade and bracket numbers.

16. Install the Alemite fittings in the spider.

17. Put on the front half of the barrel. See that the numbers on each arm correspond to the blade and bracket numbers. As the front half of the barrel is tapped down on the assembly, rotate the blades slightly to prevent contact between the barrel and the bracket arms.

18. Install and tighten the barrel bolts in their respectively numbered barrel holes. Use a wrench having not more than a 14-in. leverage. At this point check the tightness of the fit of the blades in the hub assembly by measuring the amount of torque necessary to turn each blade. (If a propeller has just been received from the factory and is being assembled for the first time, this measurement is not necessary.)

Use a lever arm clamped to the blade with a spring scale on the other end. Apply sufficient pull on the scales to turn the blade. This pull (in pounds) multiplied by the distance (in feet) from the point of application to the center line of the blade is the torque (in pound-feet). It should not be more than 90 nor less than 50 lb-ft.

If the torque on one or both blades is not within this range, the propeller must be disassembled. Corrections can be made by peeling the laminated

shims, if the reading is too high; by putting in thicker laminated shims, if the reading is too low. *Do not reduce the thickness of the oilite shim plates to obtain the correct torque.*

19. Assemble the cylinder, piston, spacer, and front cone. Make certain that the numbers on the cylinder arms match the brackets.

20. Tighten the piston on the splined bushing.

21. Install the cylinder bearing shaft thrust bearing assemblies in the bearing shaft bushings.

22. Install the counterweight bearings, bearing shafts, and oilite thrust washers. See that the number of each shaft corresponds with the number on the cylinder.

In assembling this bearing, care must be taken to see that the grooves of the races are properly related to the curve of the retainer. To check this assembly, roll the cap race back and forth—it should roll smoothly with no

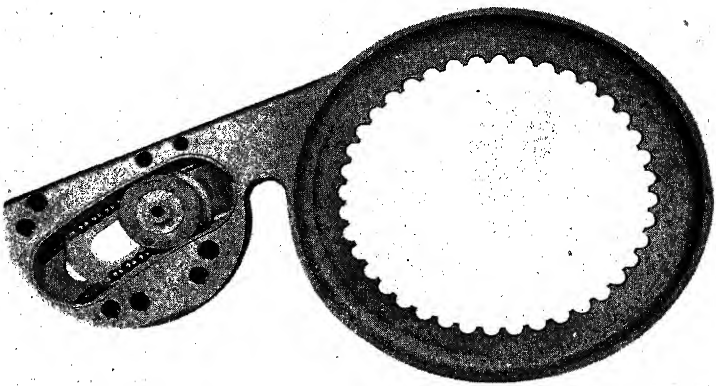


FIG. 16.—Assembly of counterweight bearings.

binding. An assembly indicator arc is stamped on the outer face of the cap race indicating the curves (see Fig. 16). After tightening the shaft, inspect the cap race to see that the curve of this indicator arc agrees with the bend of the retainer. Coat the bearings and races with lubricant.

23. Lock the counterweight bearing shafts in the cylinder with the cotter pins.

24. Slip the spacers into place in the counterweight bracket slots and put on the counterweights, being sure that each is on the correspondingly numbered bracket.

25. Place the adjusting screws in the counterweight slots. Be sure that the settings of each are correct.

26. Screw the counterweight caps on the counterweights.

27. Install the inboard (long-flanged) piston gasket on the piston.

28. Work the cylinder up and down once or twice.

The propeller is now ready to have its blade angles checked and to be dry balanced. See Balancing, and Blade Angle Adjustments, pages 450, 451.

After the propeller has been balanced and the plate angles have been checked, it should be placed on the spindle of the checking table and greased.

The propeller should be completely disassembled for greasing. Replace the Alemite fittings with pipe extensions long enough to reach through the micarta barrel supports. After filling the blade bushings to within 2 in. of the top with Mobilgrease No. 2, or its equivalent, the blades should be shoved on the spider arms. Excess grease will be forced out through the pipe extensions. The assembly should now proceed as outlined, beginning with step 13.

29. Unscrew the piston from the splined bushing and lift the propeller to one side.

30. After oiling the split front cone, hold the piston in the cylinder and place the lock ring, snap ring, spacer (if used), and the split cone (with its washer, if one is used) on the piston.

31. Install the piston gaskets, piston gasket nut, and, on Wright engines, the oil pipe washer and packing nut.

32. Put the cylinder head gasket in place, screw on the cylinder head and fasten with its lock wire.

Removal from Crankshaft.

1. Disengage the cylinder head lock wire and remove the cylinder head. Have a pail handy to catch the oil from the cylinder.

Note: On Wright engines, loosen the oil supply pipe packing nut and unscrew the piston gasket nut.

2. Disengage the piston lock ring by removing the cotter pins. It is good practice to slide the lock ring up on the piston, and safety it there.

3. Unscrew the piston. This will start the propeller off the engine shaft.

4. Slide the propeller slowly forward on the engine shaft and remove. Take care not to damage the engine shaft threads. On Wright engines care must be taken not to hit the oil supply pipe.

Disassembly.—The following steps will complete the disassembly of the propeller after its removal from the engine crankshaft:

1. Uncotter and remove the counterweight cap clevis pins.
2. Unscrew the counterweight caps.
3. *Check and record the blade angle settings* as indicated by the position of the adjusting nuts with relation to the scale stamped on the counterweights.
4. Remove the adjusting screws.
5. Take off the counterweights, and slide the spacers out.
6. Pull out the counterweight bearing shaft cotter pins.
7. Unscrew the counterweight bearing shafts. Take care that the oilite thrust washers do not fall.
8. Disengage the snap ring and the piston lock ring from the spider.
9. Lift the piston-cylinder assembly. Care should be taken that the cylinder bearing shaft thrust bearing assemblies do not fall out of the bearing shaft bushings and that the split front cone does not slip off the piston.
10. Remove the barrel bolts.
11. Split the halves of the barrel using a brass or aluminum drift at the places designed for this.
12. Drift off the front half of the barrel. Take care to keep the bracket arms from contacting the barrel as it is drifted up.
13. Drift off the rear half of the barrel. The thrust retainers will fall when the rear half of the barrel drops off unless they are held.
14. Wrap the blade shanks with cloth to prevent the steel thrust races from marring or injuring them.

15. Remove the Alemite fittings.
16. Pull off the blades.
17. Remove the oilite and laminated shim plates. Keep these in pairs and numbered so that they may be reassembled on the proper spider arms. (The laminated shims may have to be replaced if this is an overhaul.)
18. Remove the micarta barrel supports.
19. Remove the micarta spider ring.
20. Remove the leather grease retainers.
21. Note and record the indexing of the brackets with respect to the blade bushings.
22. Remove the brackets. Take care that no index pins are lost as the brackets are drifted off the blade bushings.

Hamilton Standard B Shank Propellers. *The 2B20 (8 and 15 deg.).*—Bronze cylinder bearing shaft bushings are used in this propeller instead of the ball-bearing assemblies. The blade bushings are flush with the butt face of the blades; keys, rather than index pins, are used to make the index setting.

This propeller can be furnished with two different types of pistons; one for engines having crankshaft ventilation and the other for engines not having this requirement.

The split front cone is furnished with the propeller.

Removal from crankshaft, disassembly, and installation are the same as for 12D40 and 12D30 propellers. Assembly is also the same except that the torque should be 25 to 50 lb.-ft. instead of 50 to 90 lb.-ft.

Lubrication

If the blade bushings have been thoroughly filled with grease at assembly, very little Zerking is necessary between overhaul periods, as the leather grease retainers prevent any grease being thrown from the propeller. It is recommended that propellers be checked every 50 hr. with the Zerk gun to make certain that the blade cavities are completely filled.

Warning.—Some operators Zerk each blade until grease shows around the shim plates. Grease retainers, however, prevent grease from reaching the shim plates, and this practice cannot be followed with them. Excessive Zerking may cause the blade plugs to buckle under the pressure, allowing grease to flow out in the hollow portion of the blades and causing unbalance.

Counterweight bearing assemblies should be coated with grease every 10 hr. At overhaul periods, the oilite shim plates and thrust washers should be soaked in hot oil (engine oil is suitable) for 24 hr. This will renew the self-lubricating quality of the oilite material. Mobilgrease No. 2 and Intava grease A, or the equivalent, may be used in the spider arms, blade bushings, and counterweights.

Balancing Propellers.—Use the splined bushing and mandrel for mounting propellers on the balancing stand shown in Fig. 11.

In order to permit the use of a balancing mandrel, a "dummy" piston must be installed in the 3E50, 2E40, and 3D40 propellers.

Dry Balance.—1. Coat the bearing surfaces and shim plates with a light film of grease.

2. Completely assemble the propeller on the splined bushing and checking table except for the cylinder head and, in the case of a 3E50, 2E40, or 3D40, the spring return assembly.

3. Shift the blades to high pitch and check the blade angles at the 42-in. station to be sure that they are all approximately the same.

4. Remove the propeller from the checking table and insert the mandrel in the splined bushing.
5. Place the propeller on the balancing stand. Be sure that it is true.
6. There should be no drafts or air currents near the balancing stand.
7. Check each blade in a horizontal position. The propeller should show no tendency to rotate.
8. Recheck the horizontal balance, and the stand, by repeating step 7 to the other side.
9. On two-way propellers check only the vertical balance with the blades perpendicular to the plane of the knife edges. There should be no tendency for the propeller to rotate. *This* is not done with three-way propellers.

Horizontal balance may be obtained by inserting lead wool in the hollow barrel bolts on the light side of the assembly or by removing lead wool from the barrel bolts on the heavy side. Figure 46 shows a balancing stand. In case this is not sufficient, the propeller must be disassembled and balancing washers added or removed from the blade plug of the light or heavy blade; it should then be reassembled and placed on the balancing stand, and the final balance obtained with the lead wool.

Wet Balance.—After the propeller has been balanced dry, it is placed on the checking table, disassembled, the blade bushings filled with grease, reassembled, and the high- and low-pitch angles set accurately. After setting the angles, the propeller should be balanced. This is done to make sure that all the blades are filled with grease. If a blade is light, it should be Zerked. *Under no condition should lead wool be used during wet balance.* Balance is obtained solely by Zerking more grease into the light blade.

Blade Angle Adjustments: Base Setting—Index-pin Type.—The angle at which the counterweight brackets are attached to the blades is the base or index setting. It is referred to in terms of blade angle at 42 in. radius. On the *E* and *D* shank blades the counterweight brackets are indexed to the blades by means of index pins (four for each blade) which fit in semicircular holes in the brackets and corresponding holes in the blade bushings. On the *B* shank blades the brackets are indexed to the blades by keys (two for each blade).

Both types are illustrated in Fig. 15. The *E* shank blade is shown with its counterweight bracket indexed to a base setting of 23 deg. The semicircle holes in the bracket are numbered and the holes in the blade bushing have corresponding numbers. *These numbers mean blade angle at 42 in. radius.* To index, move the bracket around on the butt of the blade until the desired numbers coincide, insert an index pin here and additional pins at the three other points (90 deg. apart), where the holes coincide.

Constant-speed Propeller Control

This is a device for use with the Hamilton Standard propellers to maintain automatically a constant engine r.p.m., at any speed selected by the pilot. It automatically changes the blade angles to meet new conditions of altitude, the attitude of the plane, or the setting of the throttle. The blade angles are set automatically to maintain a constant engine r.p.m. under all normal conditions from take-off to a descent with power. It secures greater efficiency then is possible with a fixed or a two-position propeller.

The control unit is seen in Figs. 17 and 18 with the parts named. Figures 19, 20, and 21 show the operation.

Engine oil enters at the base and goes to the low-pressure side of the booster gear pump. From here the oil goes past the relief valve, into the hollow drive gear shaft, through parts located in the upper part of the shaft. The position of the pilot valve depends on the relation of the centrifugal force generated by the flyballs to the force exerted by the compression of the speeder spring. Unbalance in the flyball speeder spring forces will allow one of the two forces to override the other and cause the pilot valve to open, or close, the propeller parts in the drive gear shaft.

Figures 19, 20, and 21 show the three conditions of operation. "On … (Fig. 19) shows the flyballs vertical, exerting a constant force against

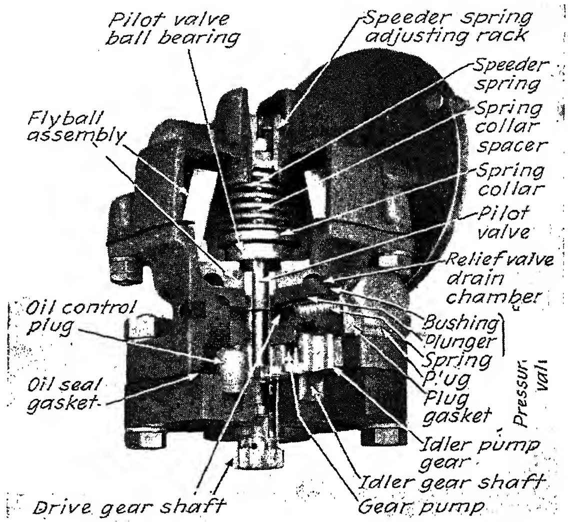


FIG. 17.—Front view of control unit.

the balancing compression of the speeder spring. The propeller parts in the drive gear shaft are just closed by the pilot valve.

A small decrease in engine speed, such as from a steep climb or when the throttle is closed slightly, brings the flyballs *in*, as in Fig. 20. The speeder spring overrides the flyballs and forces the pilot valve down. This admits oil *to* the propeller cylinder and moves the blades to a lower pitch. The engine can then return to its normal speed.

Nosing the plane down, or opening the throttle, increases the engine speed and the flyballs go *out* as in Fig. 21. This lifts the pilot valve and opens the propeller parts to the drain position. Oil flows *from* the propeller cylinder and the blades move to a higher pitch until the engine resumes normal speed.

Mechanical Cockpit Control.—Control of the constant-speed units can be either mechanical or electrical. Manual control by mechanical

means must permit the pilot to adjust the r.p.m. of the engine accurately and conveniently.

Three methods are used, depending on the type of engine and plane. These are shown in Figs. 22, 23, and 24. The method shown in Fig. 22 is recommended wherever it can be used. It is simple, easily installed, and adjusted so as to prevent or remove lost motion.

The proper sizes of cables and pulleys must be selected so that cable loading and stretch shall be small. Nineteen-strand steel cable is suggested. A chart shows that the larger the pulley the smaller the cable that can be used. Figure 22 shows the pulley sizes as compared with the pulley on the

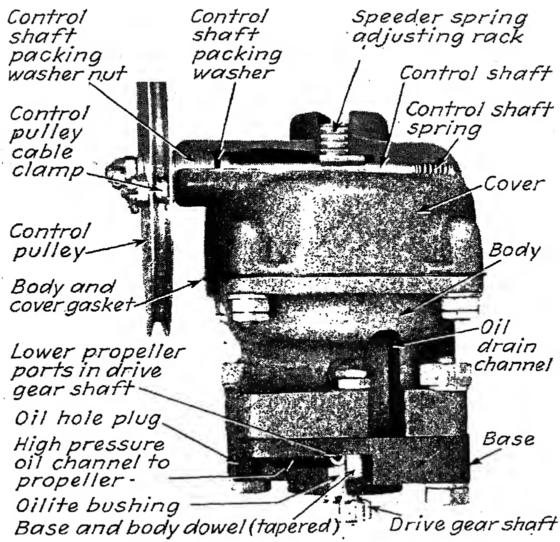


FIG. 18.—Rear view of control unit.

control unit. Figure 23 shows a lever and connecting link control; Fig. 24, the use of torque rods and universal joints.

Hamilton Standard Model 1A1 Constant-speed Control Unit. *Installation.*—The following procedure is recommended in installing the Hamilton Standard constant-speed control unit.

1. The clearance between the circular lining boss and recess in the engine mount should permit an easy fit. The outside of the lining boss can be reduced if necessary.

2. There should be general freedom between the control unit drive gear and the engine drive. Remove the cover section and turn the flyball cup assembly to see that the original backlash is maintained as the mounting nuts are tightened. Do not tighten them excessively.

3. Turn the engine crankshaft to at least three different positions and check the backlash at these points.

Removing from Engine.—1. Disconnect cockpit control from the unit.
2. Disconnect the pipe connections, if any.
3. Remove the four mounting stud nuts.
4. Remove the control unit.

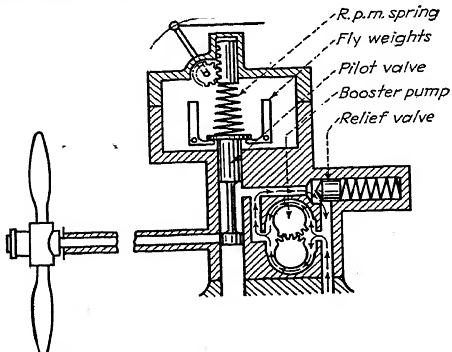


Fig. 19.—Diagram showing the propeller line closed to maintain pitch.

If the fit is so close that it is impossible to raise the unit high enough to clear the mounting studs, remove the cover section of the unit by taking off the nuts that hold the cover. As the cover section is lifted, the control shaft should be turned in the counterclockwise direction. This disengages the speeder spring adjusting rack and the control shaft. If the cover sec-

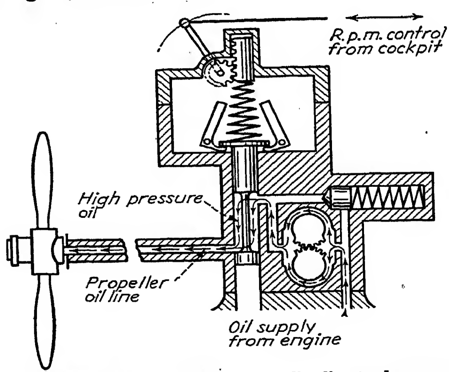


Fig. 20.—Here high-pressure oil enters propeller line to *decrease* the pitch.

tion is removed with the pilot valve spring collar assembly, it cannot be raised high enough to pull the pilot valve out of the drive gear shaft and still keep the two parts in alignment. If the alignment is not kept, side loads may bend the spring collar spindle.

Should it be necessary to remove a unit between engine overhauls, move the control pulley to high-pitch position and mark it so it can be replaced in exactly the same position.

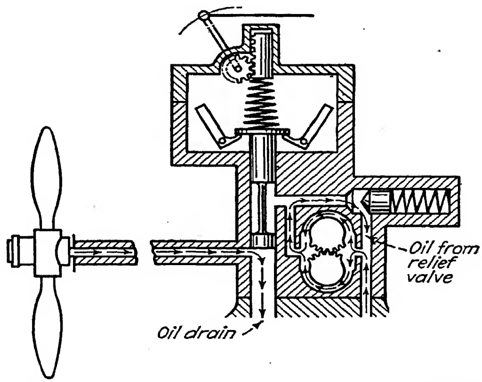


FIG. 21.—Here oil drains from the propeller line to *increase* pitch.

Electrically Controlled Units.—Electrically controlled constant-speed units use 12- and 24-volt direct current. The wiring diagram is seen in Fig. 25. The electric unit is mounted on the standard pad on the nose of the engine, in the same way as the mechanically controlled unit. No outside

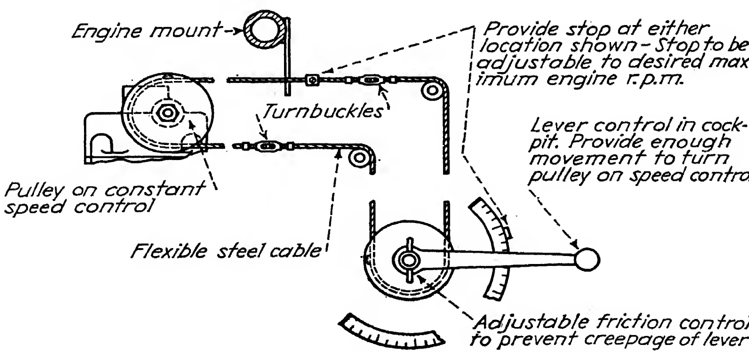


FIG. 22.—A simple cable mechanical cockpit control. This is recommended where it is possible to use it.

oil lines are needed. The oil comes through passages in the engine case to the base of the constant-speed unit. The unit is controlled electrically instead of by cables or push rods.

With 12 volts, direct current, all conductors should be No. 16 copper or No. 14 aluminum, unless the distance between the constant-speed unit, the

electrical supply, and the control switch is more than 65 ft. If more than that, use No. 14 copper or No. 12 aluminum wire. On long leads the use of aluminum saves considerable weight.

Inspection and Maintenance.—The constant-speed control is a self-contained unit working in oil, and is subjected to little wear. The only inspec-

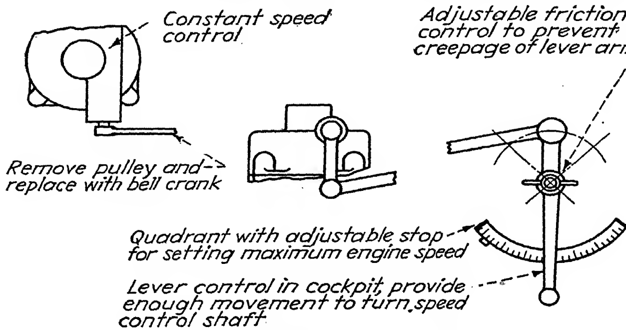


FIG. 23.—Push-pull rod cockpit control.

tion necessary between overhauls, is a visual examinaton to see that there are no external oil leaks and that the control system is free from lost motion. In cases where external piping is required, special attention should be given to the high-pressure oil line to be sure that it is securely mounted and not

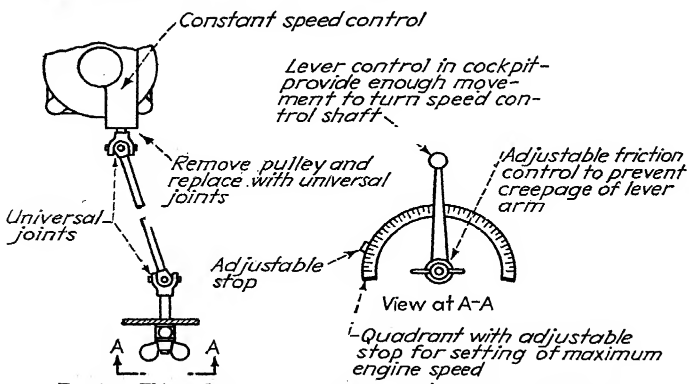


FIG. 24.—This cockpit control uses torque tubes and universal joints.

subjected to excessive vibrations that might cause failure. Maintenance at overhaul periods consists mainly of cleaning the unit. The following parts, however, should be inspected for wear:

1. The pilot valve ball bearing should be cleaned and carefully examined to ensure good condition. This part should be replaced if found worn.

2. The threads on the upper end of the spring collar should be examined to be sure that they have not been worn by the pilot valve nut. If worn, the pilot valve spring collar assembly should be replaced.

3. The spring collar spacer and the oil pressure relief valve plunger should be inspected for indications of scoring. If these units show signs of being scored, they should be polished with fine emery and crocus cloth.

4. The idler gear shaft should be inspected for side wear. If it shows indications of being worn, the shaft should be replaced.

5. The teeth of the control shaft should be inspected for wear. This shaft is plated and the wearing off of the plating should not be confused with actual wearing of the teeth. This shaft should be replaced if the teeth are badly

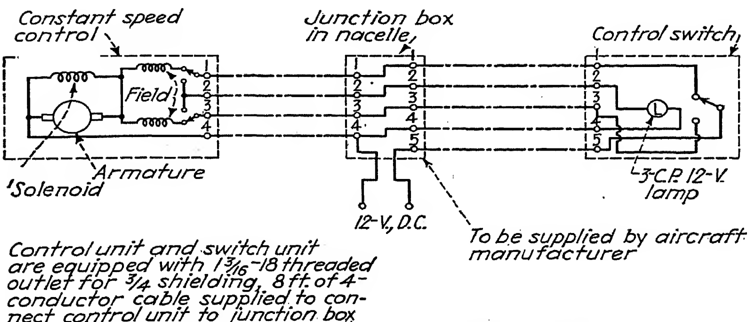


FIG. 25.—Wiring diagram of electrically controlled constant-speed unit.

6. The test stand run-up of the unit will check the wear on the gear pump, the fit of the pilot valve in the drive gear shaft, and the oil pressure relief valve assembly.

Hamilton Standard Specification No. 14

Acceptance Test for Constant-speed Controls.—This applies to both new and serviced constant-speed controls. Each constant-speed control should be subjected to a 1 hr. of continuous run, after which it should be tested to ensure that the control complies with the following requirements:

1. The internal leakage, when operating at 1,750 r.p.m. and at a pressure between 180 and 200 lb. per sq. in., does not exceed 20 qt.[1] per hr. with the governor set in positive low-pitch position.

2. The relief valve is set to maintain a pump pressure of from 180 to 200 lb. per sq. in.

3. There is no external leakage when the pump chamber and oil passages are subjected to a pressure of 400 lb. per sq. in.

4. The pump capacity is not less than 8 qt. per min. at 175 deg. r.p.m., at a back pressure of 150 lb. per sq. in.

5. All the above tests are to be conducted at room temperature, using an oil of approximately S.A.E. No. 10 viscosity.

6. A record of the above data is to be made on a suitable form and filed with the parts list applying to each governor assembled.

[1] For serviced controls, 30 qt. per hr. is permissible.

7. Name plates bearing the model and serial numbers of the governor are to be fastened on each unit.

It is also essential that the unit be carefully checked to be sure that there are no external oil leaks. The point at which leaks are most likely to occur is at the joining surfaces of the mounting base and at the control shaft.

Constant-speed controls that do not meet the above requirements should be returned to the factory for overhaul.

These units, like all other aircraft devices, are constantly being improved and Fig. 26 shows the latest design of Hamilton Standard propeller-control

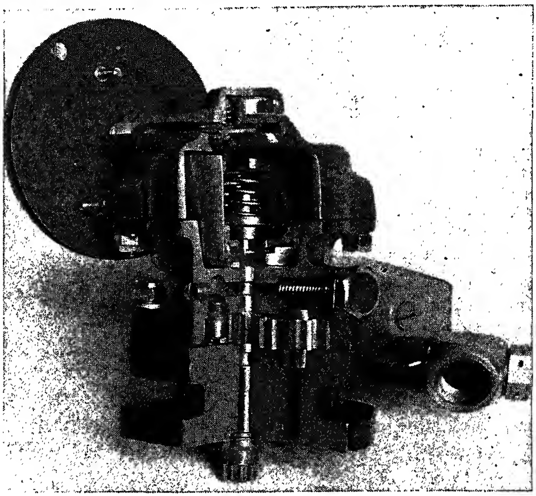


Fig. 26.—The latest design of Hamilton-Standard propeller control unit.

unit. Although there are no radical changes, they represent a steady advance in better and safer flying.

Hydromatic Quick-feathering Propeller

This, the latest Hamilton Standard propeller, includes constant control by which the blades can be turned so that they lie in the direction of flight, which is called "feathering." This acts as a powerful brake to stop the engine and also reduces air resistance. The ability to stop a disabled engine of a multiengined plane makes the remaining engines more effective and prevents damage to the disabled engine. Figure 27 shows the safety feature of feathering the propeller. Where repairs can be made in flight, the propeller can then be shifted to its normal pitch, when it will "windmill" and crank the engine.

A cutaway view of this mechanism is seen in Fig. 28. The operation is shown in Fig. 29. This shows only the movable cam which is geared to the hub of the propeller blades. Outside of this, as can be seen in Fig. 28, there is a stationary cam with the slots in the opposite direction. The rollers

(shown in Fig. 29) bear in both cams, and turn the inner cam when moved by the piston.

Feathering control is manual by the pilot through the auxiliary control mechanism, shown in Fig. 30. This shows the individual pump system.

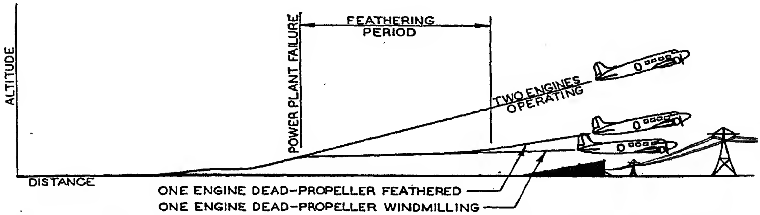


FIG. 27.—Diagram showing the advantage of a quick-feathering propeller when one engine goes dead at the take-off.

The pilot closes switch C which closes the electrical circuit from ground G, through battery B, switch C, solenoid switch S, to ground F. This completes the circuit and starts the high-pressure oil pumps. The flow of current also energizes the coil H which holds switch C closed. The pump now runs without attention from the pilot and supplies oil to governor cut-off value 5 (Fig. 29) through line 28.

At about 150 lb. pressure, valve 5 disconnects the governor from the system by closing the port. At the same time the valve connects the pump with the inner end of the propeller cylinder through the same passages that carry oil to the propeller for constant-speed operation. As the piston moves out, the blades are feathered, the speed depending on the oil pressure which cannot exceed 400 lb. At this pressure, port 10, leading to the inner end of the cylinder is closed. Oil in the outer end of the cylinder goes into the engine lubricating system.

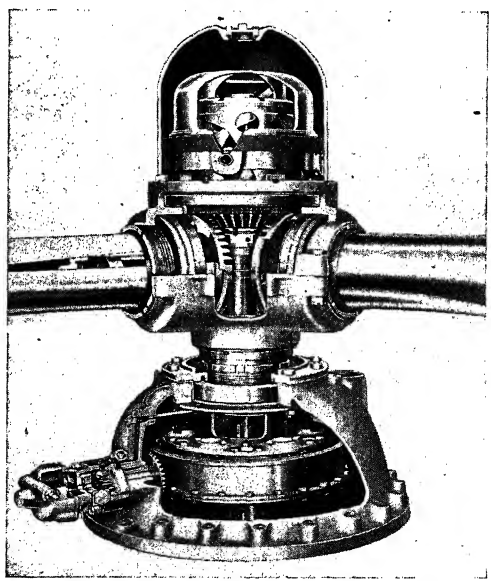


FIG. 28.—Cut-away view of hydromatic propeller.

When the oil pressure has feathered the propeller, it builds up to 400 lb. and opens the cutout switch E (Fig. 30). This deenergizes coil H, allowing

cutoff switch C to return to normal. Coil K is deenergized, the motor circuit is broken, and the pump stops. The pressure drops to zero on both

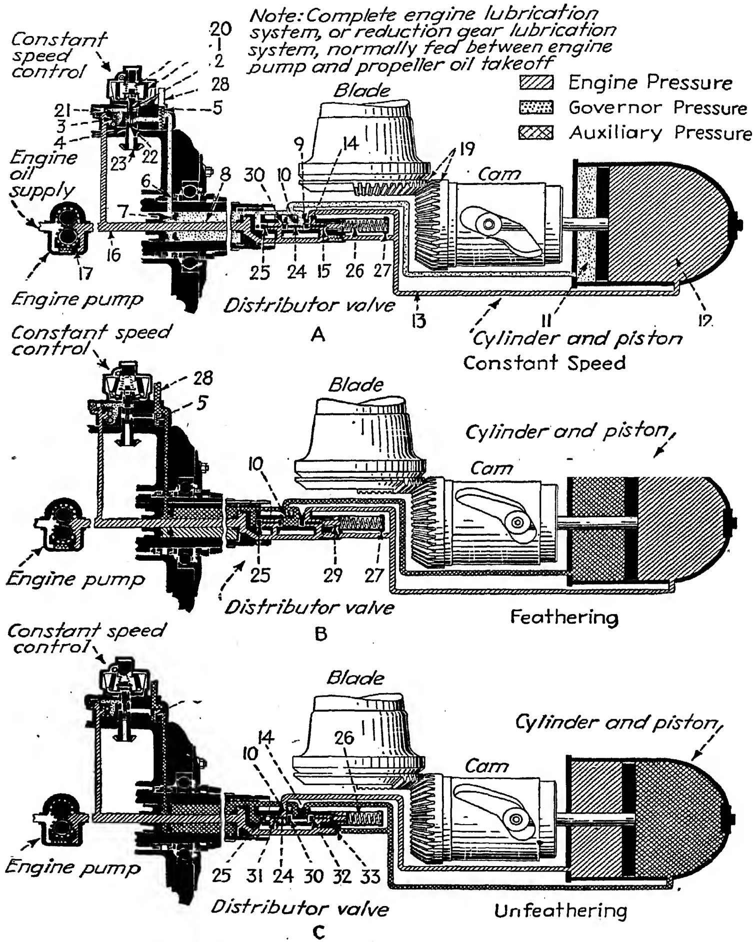


FIG. 29.—These three views, *A*, *B*, and *C*, show the operation of the feathering mechanism. See numbered list of parts on opposite page.

sides of the piston but the wind pressure on each side of the blade holds the propeller in position.

Reversing the passages in the distributor valve unfeathers the propeller by permitting high-pressure oil to act on the outer end of the piston, while the inboard side is connected to the engine lubricating system. Engine oil pressure is used only to assist in turning the blades toward low pitch. The entire control of the propeller during constant speed, feathering, and unfeathering is by a single oil passage between the governor base and the propeller. Variations in pressure and volume of oil flow control the propeller.

On engines that breathe through the propeller shaft, make sure that the breather tube on the front end of the valve assembly is properly started in the hole in the front end of the dome.

Turning the dome assembly in a clockwise direction in order to align the dowels and holes should be avoided, as this will tend to move the stop lugs on the rotating cam away from the high-pitch position and allow the gears to mesh incorrectly.

In some cases, depending on the blade design, it is necessary to limit the full-feathering blade angle to slightly more or less than 90 deg. (at the 42-in. station) in order to eliminate any tendency of the propeller to windmill forward or backward when feathered. Propellers, in these cases, are provided with stop pins which limit the blade angle to other than 90 deg.

Tighten the dome retaining nut, using the proper wrench, in the manner indicated by tightening the propeller retaining nut by applying a force of approximately 180 lb. at approximately 4-ft. radius. With the dome assembly properly seated in the barrel, the front face of the dome retaining nut will be approximately flush with the front edge of the barrel.

It is essential that the dome unit be firmly seated on the retaining shoulder in the barrel. Tightening the dome retaining nut, in addition to fastening the dome unit to the hub, serves to apply the preloading force to the gears and to compress the dome and barrel seal. Its tightening, therefore, requires a relatively high wrench torque as indicated above. Failure to tighten the dome unit securely in the hub will result in elongation or failure of the assembly screws that fasten the dome cylinder and the stop locating plate to the stationary cam.

Install the dome retaining nut lockscrew and safety the screw with a $\frac{1}{16} \times \frac{1}{2}$-in. steel cotter pin.

On engines that do not breathe through the propeller shaft, make sure that the dome breather hole nut in the front of the dome is tight and that the lock wire is in place.

On engines that breathe through the propeller shaft, insert the gasket between the breather tube and the front end of the dome. Install the breather cup and safety it with the locking ring provided.

1. Governor flyweight.
2. Governor pilot valve.
3. Governor pump.
4. Hollow drive shaft.
5. Governor cut-off valve.
6. Engine-shaft oil-transfer rings.
7. Propeller-shaft air-separator plug.
8. Propeller-shaft oil passage.
9. Distributor valve port.
10. Distributor valve port.
11. Propeller cylinder—inboard end.
12. Propeller cylinder—outboard end.
13. Oil-supply tube—outboard cylinder end (schematic only).
14. Distributor-valve port.
15. Distributor-valve port.
16. Engine oil-pressure supply tube.
17. Engine-pump relief valve.
18. Cam slot rollers.
19. Bevel gears.
20. Governor control spring.
21. Governor relief valve.
22. Governor drain port.
23. Governor drive gear.
24. Propeller distributor valve.
25. Propeller distributor valve.
26. Distributor-valve spring.
27. Distributor-valve spring housing.
28. External high-pressure oil line.
29. Distributor-valve (outboard end)
30. Distributor-valve land.
31. Distributor-valve port.
32. Distributor-valve land.
33. Dome pressure relief valve.

Caution. Using suitable levers to turn the blades, shift the propeller into full low pitch and check all three blade angles by the index lines on the blades and the graduations on the barrel or with a protractor. These angles should be equal and should agree with the low-pitch stop setting.

This check indicates that the correct relationship between the blade gears and the cam gear has been obtained.

Check all external lock wires and cotter pins.

Nonfeathering Propellers.—Should it be desired to operate the propeller without the feathering feature, the high-pitch stop may be adjusted to limit the high pitch to any angle below 45 deg.

In order to assemble the propeller with a feathering (or high-pitch) angle less than 90 deg., the same general procedure as indicated above should be

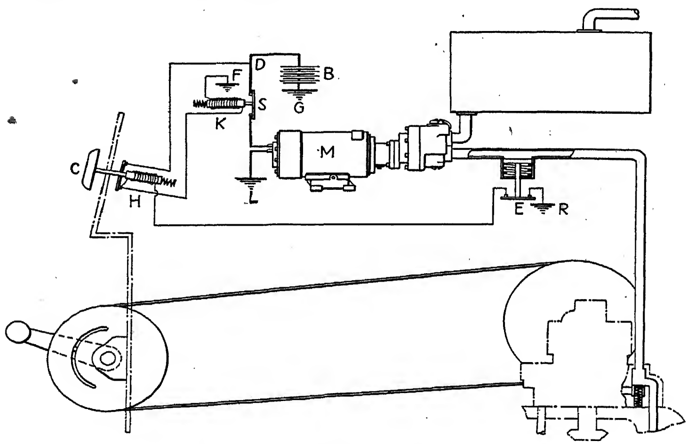


FIG. 30.—The auxiliary control system.

followed, with two exceptions, namely, (1) instead of turning the blades against the 90-deg. stop pins, they must be turned against the lower degree stop pin or set to the specified blade angle (at the 42-in. station) by means of the graduations on the barrel and the index lines on the blades, or by means of a protractor; (2) the high-pitch stop ring must be set to this same blade angle by inserting it so the arrow on the stop is aligned with the corresponding degree mark on the stop locating plate.

The dome assembly may then be installed in the hub as indicated above.

Note: Prior to feathering and unfeathering a propeller for test after installation, the engine should be started and the propeller operated under constant-speed control. This will ensure that the dome and barrel are filled with engine oil and that all parts of the propeller are fully lubricated. A smaller amount of oil will then be necessary to feather and unfeather as the dome and barrel will have been filled with engine oil; therefore, the demand on the auxiliary pressure system will be less.

Removal Instructions.—The procedure for removing the propeller from the propeller shaft is, in general, the reverse of the installation procedure.

1. For installations on engines that breathe through the propeller shaft, remove the lock ring and breather cup from the front of the dome.
2. Remove the lock screw from the dome retaining nut and unscrew the nut. This nut is attached to the dome and acts as a puller when the nut is unscrewed.
3. Remove the dome assembly.
4. Remove the lock ring from the propeller retaining nut.
5. Unscrew the valve assembly.
6. Unscrew the propeller retaining nut and remove the propeller from the shaft.

Note: The hub snap ring and related parts inside the spider are so arranged that, as the retaining nut is backed off, it pulls the propeller with it until the nut reaches the end of the propeller shaft thread.

How It Works.—The pitch control mechanism of the Hydromatic propeller retains the rugged hydraulic type control whereby the pitch of the

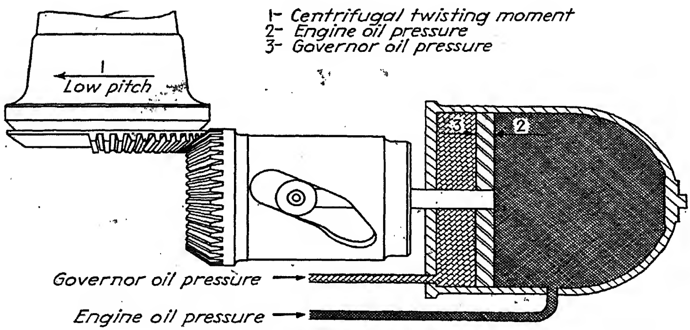


FIG. 31.—Diagram of propeller-control forces.

propeller blades is controlled by a precision type governor to obtain constant engine speed and synchronization of the propellers of a multiengine airplane.

Three fundamental forces are used to control the blade angle. They are (1) centrifugal twisting moment of the blades toward low pitch which is utilized to decrease the blade angle; (2) engine oil under normal engine pressure which supplements the centrifugal moment, thus ensuring adequate control force toward low pitch at low propeller speeds; (3) engine oil under *boosted* pressure from the governor which moves the blades toward high pitch. These forces are indicated in Fig. 31.

The necessary balance between these control forces is maintained by the propeller governor which, in addition to boosting the engine oil pressure, meters to, or drains from, the propeller the quantity of oil required to maintain the proper blade angle for constant-speed operation.

When it is desired to feather the blades, an auxiliary pressure supply system is necessary. This consists of an independent oil supply with a provision for manual control by the pilot to provide up to 400 lb. for feathering and 600 lb. pressure for unfeathering. When, during the unfeathering operation, the propeller blades have been moved into the flight operating range, normal constant-speed control automatically becomes available.

Hydromatic Propeller Assembly.—Assembly of the Hydromatic propeller should be done in the following order. Be sure all parts are free from grit and lubricated with a thin coating of engine oil unless otherwise noted in these instructions.

Barrel and Spider Alignment.—1. Install a splined sleeve in the spider.

2. Insert the flange of the propeller retaining nut in the corresponding grooves in the split front cone and install this assembly in the spider. Run the nut down snugly on the sleeve using proper wrenches.

3. Install the split phenolic spider ring in the recess near the bottom of the spider so that the three flats on the ring register with the shim plate bearing surfaces on the spider.

4. Coat three 0.005-in. barrel support shims with grease and place them on the spider between the arms.

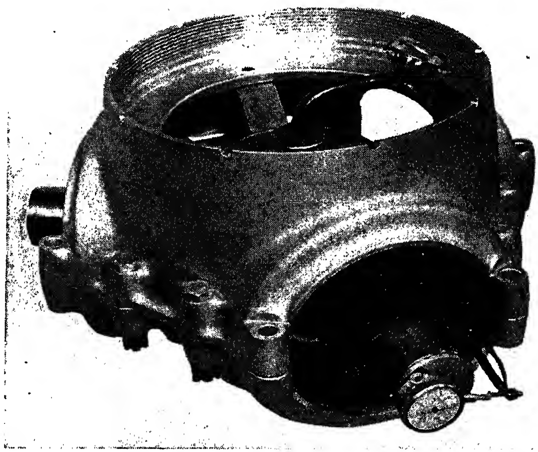


FIG. 32.—Using indicator to check barrel and spider alignment.

5. Install the three barrel supports over these shims with the flat ends toward the front of the spider.

6. Place the spider assembly in the rear half of the barrel and install the front half of the barrel over it. The barrel and spider should be assembled so that the numbers 1, 2, and 3 on the parting surface of each barrel half at the blade sockets correspond with the same numbers on the spider arms.

7. Secure the barrel halves together with six barrel bolts, two center bolts on each side of the barrel, drawn up tightly.

8. With an indicator (Fig. 32) check the concentricity of an arbor through the splined sleeve with the inside surface of the front barrel half just forward of the dome shelf. The eccentricity must not exceed 0.003 in. full indicator reading.

Adjustment is obtained by varying the barrel support shim thicknesses. For the final assembly, one solid shim, of thickness not less than 0.005 in.,

is to be used under each support block. These shims may be obtained in 0.001-in. increments from 0.005 to 0.015 in.

9. Number the blocks and shims 1, 2, and 3 in counterclockwise rotation starting with No. 1 between spider arms 1 and 2 and stamp the same numbers on the top chamfer of the spider.

10. Remove the arbor and install the assembly on the assembly post.

11. Remove the front half of the barrel and drop the rear half.

Blade and Gear Segment Assembly.—1. Check the blade bushings to be sure that they are properly installed in the blades. Although the blade bushing appears symmetrical about its central axis, actually two of the spring pack slots are offset in order to preload the gear teeth (Fig. 33). For this reason, there is only one angular position in which the bushing may be installed for a given type of propeller. The same blade bushing may be

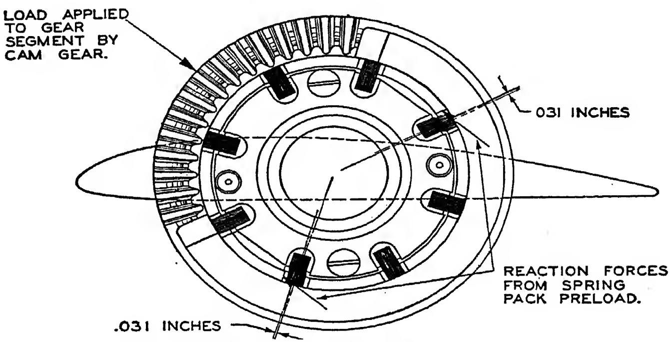


FIG. 33.—Diagram showing gear-segment preloading.

used for any of the following combinations but it is absolutely essential that its position be as follows:

a. For a right-hand screw, tractor propeller, on a right-hand engine, the bushing may be installed so that the locating arrow on the face of the bushing flange is aligned with the words "Tractor Blade" stamped on the blade butt.

b. For a right-hand screw, pusher propeller, on a left-hand engine, the same blade may be used but the arrow on the bushing must be aligned with the words "Pusher Blade" on the blade butt.

c. For a left-hand screw, tractor propeller, on a left-hand engine, a different blade is required. The bushing must be installed so that the arrow is aligned with the words "Tractor Blade" on the blade butt.

d. For a left-hand screw, pusher propeller, on a right-hand engine, the same blade may be used as for a left-hand screw, tractor propeller, on a left-hand engine, but the bushing must be installed so that the arrow is in alignment with the words "Pusher Blade" on the blade butt.

For left-hand screw propellers, left-hand stationary and rotating cams are required.

2. Install the shim plate drive pins in the holes in the blade bushing drive pins; two in each blade. These should be a light drive fit.

3. Drive the thrust plate pin into the thrust plate. Place the thrust plate on the flat of the blade bushing flange and tap it into place so that the pin is flush with or slightly below the curved surface of the thrust plate.

The thrust plate is not symmetrical and hence, if it is not properly installed, one end will overhang one of the bushing spring pack slots.

Although there are two flats on each blade bushing, only one thrust plate per blade is required and should be placed *toward the flat side of the blade on tractor propellers* and *toward the cambered side of the blade on pusher propellers*.

4. Wash all spring leaves with gasoline to remove any grit and lubricate them with engine oil. Assemble 34 spring leaves in each pair of spring retainers.

Note: Owing to manufacturing tolerances, the number of leaves required to give the proper fit in the spring retainers will vary slightly. In any case, there should be used only a sufficient number of leaves to give a snug sliding fit of the retainer over the spring leaves. Do not force too many leaves into the retainer.

5. Install the spring packs in the blade gear segments.

6. Install the gear segments on the blades so that their numbers correspond with those of the blades, and so that the arrow on each segment is in alignment with the arrow on each blade bushing. Tap the spring packs into place, using a brass drift.

7. Select a 0.015-in. shim for each blade, coat it with grease, and install it on the blade bushings over the shim plate drive pins. These shims regulate the clearance between the blade thrust bearing assembly and the barrel to compensate for manufacturing tolerances. The proper shim thickness to give the specified blade torque must be determined at assembly by trial. It has been found that a shim of 0.015 in. thickness is quite likely to give the proper torque and is recommended for the first trial assembly. After the proper torque has been obtained, number the shims to correspond to the blade numbers and remove any high spots caused by the numbering. Only one shim should be used in each blade assembly.

8. Coat the shim plates with grease and install one on each blade over the above shims. It is essential that the shim be installed as indicated, that is, *between the shim plate and the flange of the blade bushing*. Make sure that the number on the shim plate corresponds with the blade number.

Assembly of Hub and Blades.—1. With the top half of the barrel removed, install the blade assemblies on the proper spider arms, which are numbered, 1, 2, and 3 to correspond to the blade numbers. See that the "O" etched on the inside thrust race on each blade is aligned with the "O" stamped on the blade butt flange.

Before pressing the blades against the spider shim plate bearing bosses, be sure that the shims and shim plates are in their proper places over the shim plate drive pins.

2. Install the thrust bearings between the thrust bearing races on the blades, two half bearings on each blade. These bearings are interchangeable among the blades.

3. While holding the thrust bearings in place, raise the rear half of the barrel, making sure that the barrel and spider markings are in the proper relation.

The barrel should be a light drive fit over the bearing races. After properly starting the barrel over the races, drive it into place with a nonmetallic mallet.

4. Lay the barrel seals in the grooves provided in the rear barrel half, making sure that the small tips on the ends of the seals are entered in the $\frac{1}{32}$-in. diameter grooves at each blade socket.

Care should be taken to maintain the sharp edges of the parting surfaces of the barrel adjacent to the blade packings to ensure perfect oil seal.

5. Install the front barrel half on the proper angular position and drive it down until there is about $\frac{1}{2}$-in. clearance between the barrel parting surfaces.

6. Install the 12 barrel bolts which are numbered to correspond to the numbers on the spot faces on the barrel.

The three long bolts, one of which is adjacent to the leading edge of each blade, hold the de-icer discharge nozzles. When no de-icer is installed, two washers are used on each of these three bolts. The remaining nine bolts are installed without washers.

7. Check the barrel seals to be sure that they are in place and draw the barrel halves together tightly with the bolts. Tighten first the two center bolts on each side.

Avoid tightening the three barrel bolts that retain the blade seal nut locks excessively without the locks in place in order to prevent possible springing of the barrel.

8. Check the frictional blade torque. This must be between 20 and 30 lb.-ft.; that is, between 10 and 15 lb. force on a lever arm 2 ft. from the center line of the blade. If the torque of each blade does not fall between these limits, make appropriate changes in the shim thicknesses under the blade shim plates until it does.

9. Loosen the barrel bolts and spread the barrel halves about 0.010 in. at the parting line.

10. Thoroughly coat each ring of the blade packing with engine oil and insert in the space provided between the barrel and the blade chafing ring. The split ring of triangular cross section (header ring) enters first with the flat side toward the thrust race. Seat the ring evenly, using a brass or fiber rod, and be sure the split is overlapped in the proper manner.

The next three (lip) rings are not split and must be slipped over the blade. This may be facilitated by oiling the blade edges. Insert these rings, one at a time, with the feather edge first and seat each one with the brass rod.

The fifth packing (follower) ring is split and should be inserted with the feather edge and with the flat side against the blade packing nut. Seat this packing ring with the brass rod and be sure its split is properly overlapped.

Do not use a steel tool for seating the packings as it may scratch the sealing surfaces.

11. Split the blade packing nuts and assemble them over the blade shanks.

These split nuts are manufactured as units and both halves of each nut bear the same number at the parting line. Be sure that both halves have the same number when assembled.

12. Screw the blade packing nuts into the barrel using the special wrench until the nuts seat against the shoulder in the blade socket. Back off each nut until the first locking hole is in alignment with the space between the barrel halves provided for the lock. The shoulder in the blade socket eliminates the possibility of the packing being compressed excessively.

Under no conditions should the threads of the blade packing nuts or the corresponding threads in the barrel be rechased. The relative pitch diameters of these threads are such that the nut is firmly clamped in the barrel when the two halves of the barrel are bolted together. The thread dimen-

sions are held to close tolerances and special gages are necessary to ensure the proper clamp fit.

13. Install the three blade packing nut locks and tighten the barrel bolts securely.

14. With a protractor, set all blades at 25 deg. at the 42-in. station.

15. Remove the propeller from the assembly post.

16. Install the packing between the spider and the rear half of the barrel in the manner indicated for the blade packings.

17. Install the barrel and spider packing retainer assembly as follows:

a. Spring the rear packing gland over the rear end of the spider with the flat edge toward the packing.

b. Install the rear spider packing and de-icer spacer on the barrel with the flat face of the spacer away from the barrel and fasten it in place with eight screws, safety-wired with 0.040-in. wire.

Note: If a de-icer slinger is used, install it over the spacer, securing both the slinger and the spacer with the above screws, safety-wired with 0.040-in. wire. See De-icing Equipment.

c. While holding the packing gland gap closed, slide the rear spider packing gland retaining ring over the gland, with its flat edge toward the rear, until the locking slots in the gland and the groove in the retaining nut are aligned.

d. Install the rear spider packing gland spring lock in the assembly so that it engages the groove in the retaining ring through the slots in the gland.

When the retaining ring is properly installed, with its groove toward the rear of the propeller, its rear edge will be flush with the rear edge of the gland when the spring lock is in place.

18. Balance the assembly (see page 479).

19. After final balance, install a welch plug in each barrel bolt head.

20. Remove the arbor and splined sleeve and install the propeller on the test fixture.

21. Install the oil seal washer against the spline ends in the spider. Insert the spider-and-shaft oil seal ring in the seal and install this assembly, with the ring outermost, against the washer. Install the cone, propeller retaining nut, and the hub snap ring.

22. Test the propeller.

23. After completion of these tests, safety the barrel bolts with cotter pins.

Dome Assembly.—Before the dome is assembled, it is necessary to determine the gear preload and adjust it to within the required limits (see Assembly and Test Specifications).

1. Install the cam ball bearings in the ends of the stationary cam so that the word "Out" etched on each can be read when looking at the end of the cam.

2. Insert the rotating cam in the stationary cam and drive it into place by dropping the assembly several times from about a 1 ft. height so that the gear lands squarely on a clean hard wood block.

3. Install the cam ball bearing nut and tighten it with the special wrench sufficiently to cause the bearings to bind slightly and drop the assembly again as above.

If necessary, tighten the nut again to get the same amount of binding and *then back it off two cotter pin holes.* In this manner, the bearings will be so adjusted that the cams will rotate without binding.

4. Lock the nut with a $\frac{1}{2} \times \frac{3}{32}$-in cotter pin inserted from the outside.

5. Turn the cams so that the letters "O" etched in the bottom of one cam slot in each cam are in alignment.

6. Place four cam slot rollers on each cam slot roller bushing and install the four assemblies in the cam slots with the bushing flanges toward the outside.

7. Slip the piston over the cam assembly so that the "O" stamped on the boss of one of the cam slot roller shaft holes is in alignment with the "O" in the cam slot.

8. Insert the four cam slot roller shafts in the piston with the tapped holes toward the outside, and drive them in until their outer ends are just flush with the outer surface of the piston.

To facilitate installation of these shafts insert a ½ in.-13 U.S. standard thread bolt in the tapped hole in the end of the shaft and drive the shaft in by striking the head of the bolt with a hammer.

9. Insert the four cam slot roller shaft screws in the skirt of the piston and tighten them securely. These screws carry a pipe thread and have no additional means of locking.

10. Install the piston gasket and nut. To facilitate holding the piston while tightening this nut, it is advisable to insert a ½ in.-13 U.S. standard thread bolt in each of two opposite cam slot roller shafts. Using the special wrench with a 2-ft. bar, pull up the nut as tight as practicable and align a lock screw hole in the nut with a milled slot in the piston.

11. Insert the locking screw and safety it with a $\frac{1}{16} \times \frac{1}{2}$-in. cotter pin.

12. Install the stop plate so that the three small dowel pins in the stationary cam engage the holes provided for them in the stop plate. There is only one position for this plate on the cam as the dowel pins are not arranged symmetrically.

If any gear preloading shims are used, they should be installed between the stationary cam and the stop plate.

13. Slip the dome over the cam and piston assembly and screw into it, through the stop plate and cam base, the six flathead screws. Be sure the heads of these screws are flush with the surface of the stop plate.

14. Slip the dome retaining nut over the dome and align the hole through the threads of the nut with the milled groove in the lip of the dome ball race. Insert 98 balls and close the hole with a welch plug.

15. Insert the positive low-pitch stop ring at the specified blade angle (see Resetting the Positive Stops).

16. Insert the positive high-pitch stop ring at the specified blade angle.

17. Balance the assembly (see page 479).

18. Stretch the dome and barrel seal over the base of the stationary cam so that its unbeveled edge lies adjacent to the dome flange.

19. Install the breather hole seal in the front of the dome, the V edge going in first.

20. Install the dome breather hole nut or the dome breather cup and install the lock wire.

Valve Assembly.—1. Insert the distributor valve in the sleeve in the valve housing with the smaller end toward the Allen plug (Fig. 34).

2. Insert the spring and washer in the spring housing in the order mentioned, and lay the flat copper gasket in its place on the open end of the spring housing.

3. Hold the valve housing with the Allen plug end up and screw the spring housing in from the bottom. This procedure avoids the possibility of the washer's becoming wedged under the spring housing.

4. Tighten the spring housing until the gasket is firmly seated and safety it with 0.040-in. brass wire inserted through the hole in the valve housing which is aligned with a milled slot in the spring housing.

5. Insert the dome pressure relief valve spring and sleeve, in the order mentioned, into the valve housing, making sure that the beveled end of the bronze sleeve, which is the ball seat, is outermost. Screw the ball and plug assembly down tightly on them. Since the plug carries a pipe thread, no additional means of locking is provided.

6. Install the four oil seal ring expanders and the four oil seal rings in the grooves provided on the valve housing.

7. Install the $\frac{1}{32}$-in. copper gasket over the two dowel bushings which extend from the rear end of the valve housing.

8. Install the oil transfer plate on these bushings. These bushings are of two different diameters, as are the holes in the plate, therefore the plate can be installed in only one position.

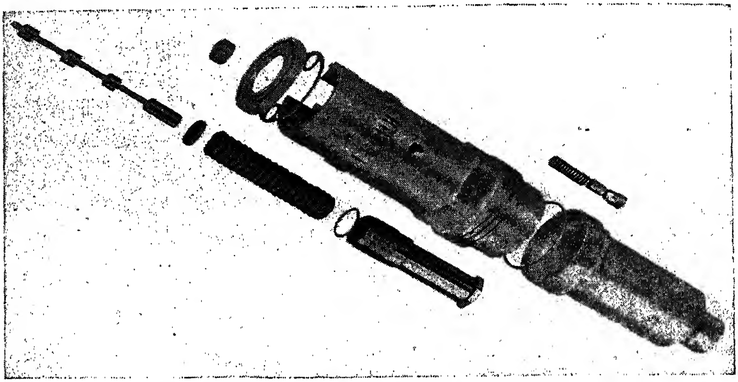


FIG. 34.—Valve assembly for engines breathing through propeller shaft.

a. For engines that breathe through the propeller shaft, the oil transfer plate has a $1\frac{1}{4}$-in. hole through its center for the passage of breather gases.

b. For engines that do not breathe through the propeller shaft, the hole does not go through the center of the plate, but connects with the dome oil pressure line in the side of the valve housing.

9. Engines that breathe through the propeller shaft require that the breather tube be installed on the valve housing. Insert the copper-asbestos gasket in the front end of the breather tube and screw the breather tube to the housing, drawing it up *tightly* and safety it with a brass wire through a slot in the skirt of the tube and the hole drilled into the dome pressure duct in the valve housing.

Resetting the Positive Stops.—1. Lift out the uppermost stop ring. This is the high-pitch stop ring and is marked "Set to High Pitch" on one lug and "Assemble This Stop Last" on the other lug (see Figs. 35 and 36).

2. Lift out the lower stop ring. This is the low-pitch stop ring and is marked "Set to Low Pitch" on one lug, and "Assemble This Stop First"

on the other lug. The stop rings may be removed by inserting No. 10-24 screws in the tapped holes provided in the rings for this purpose.

3. Reinstall the low-pitch stop ring to the desired low-pitch limit by inserting it so that the arrow on the stop ring coincides with the desired degree mark (indicating the degrees of blade angle at the 42-in. station) stamped on the top locating plate. The lowest possible setting is 10 deg. and, by inserting the stop ring so that the arrow on it is aligned with graduation "10" on the stop locating plate, the propeller will be adjusted to 10 deg. low limit. Any low limit higher than 10 deg. can be obtained by inserting the low-pitch stop ring with the arrow aligned with the desired degree mark on the stop locating plate.

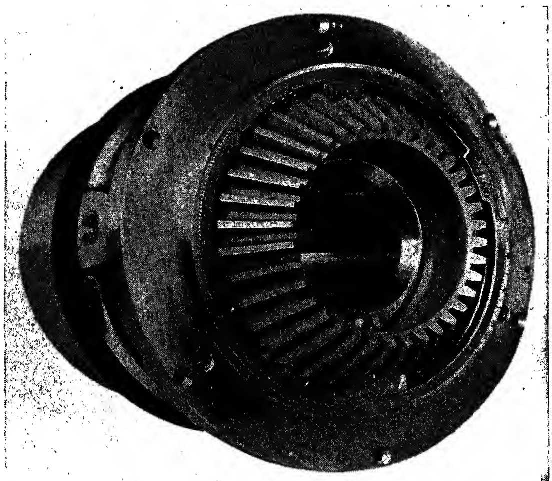


FIG. 35.—Piston and cam assembly—low-pitch position, high r.p.m. The setting is stamped on the ring outside the gear.

To insert the low-pitch stop ring, it may be necessary to rotate the cam gear a small amount in a counterclockwise direction to permit inserting the stop ring without interfering with the stop lugs on the gear. It will be noticed that this rotation causes the piston in the dome assembly to move forward.

The stop lug on the cam gear marked "Set Within Graduations" must be within the graduated arc of the stop locating plate after the stop rings have been installed.

4. Reinstall the high-pitch stop ring to the desired high-pitch limit by inserting it, on top of the low-pitch stop ring, so that the arrow on the high-pitch stop ring coincides with the desired degree mark on the stop locating plate. The highest possible setting is 90 deg. but with some blade designs the full-feathered setting is a degree or two lower than 90 deg. due to their pitch distribution which causes them to windmill backward when set to 90 deg. at the 42-in. station.

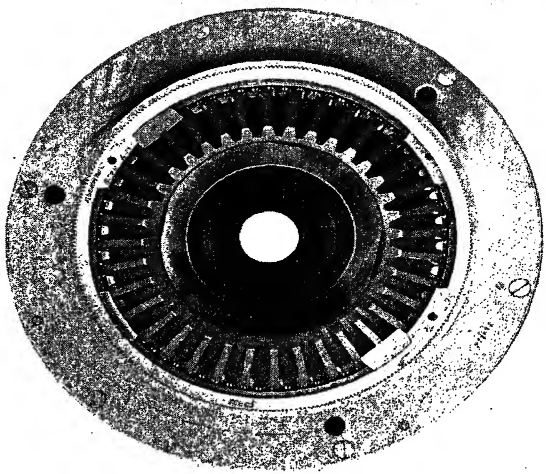


FIG. 36.—Assembly with high- and low-pitch stops.

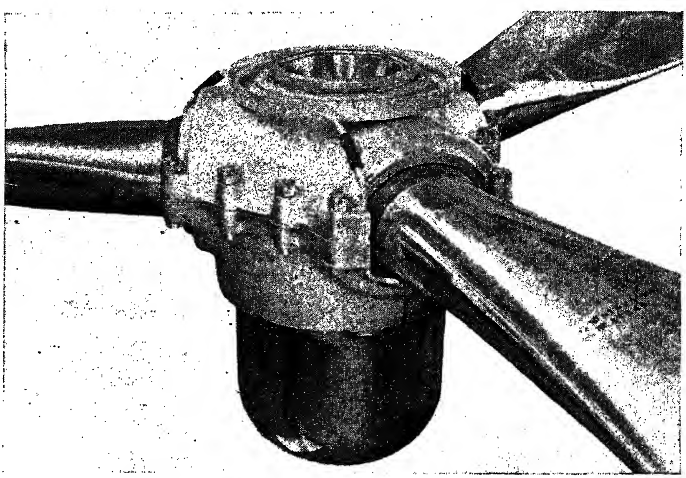


FIG. 37.—De-icer for Hamilton Standard propeller.

De-icing Equipment.—The Hamilton Standard method of preventing the formation of ice on propellers is to feed a de-icing fluid to the surface at the base of each blade. From here it is carried to the blade tip by centrifugal force. Figure 37 shows the de-icer slinger ring and the tubes that lead the fluid to the blades. Details are seen in Fig. 38.

The de-icing equipment consists of (1) a blade discharge tube and bracket assembly and (2) a slinger ring assembly.

Shield and Fender Tube Assembly.—1. After proper adjustment of the blade packing nuts and before tightening the barrel bolts, place a discharge tube bracket over the barrel bolt boss at the leading edge of each blade arm and set the clearance between the end of the tube and blade shank $\frac{1}{16}$ in.

2. Tighten the barrel bolts.

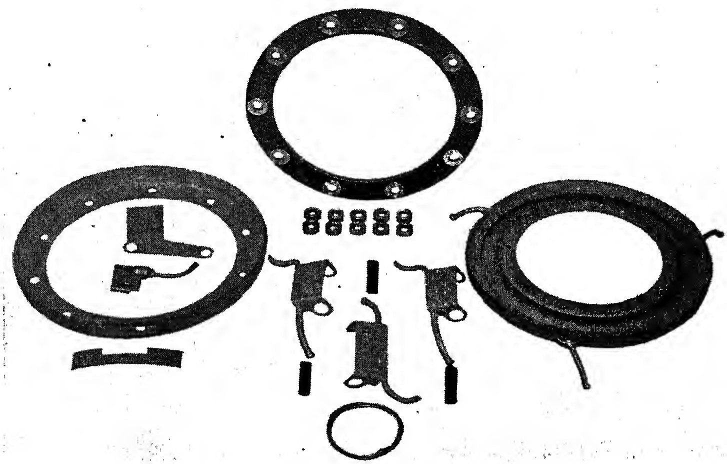


Fig. 38.—Details of parts used in the de-icer.

3. With the packing between the spider and rear barrel installed, place the slinger ring over the rear barrel packing gland and insert the eight screws through the slinger ring and plate (see assembly of Hub and Blades).

4. Connect the slinger ring nipples to the blade discharge tubes by means of hose connections. Safety-wire the hose connections in place.

5. Balance the propeller.

6. Before mounting the propeller on the engine shaft, the shield and feeder tube assembly should be mounted on the front section of the engine.

Propellers for Wright engines are supplied with a single thrust bearing cover plate to replace the one already mounted on the engine. Propellers for Pratt and Whitney engines are supplied with 10 individual spacers to replace the $\frac{3}{8}$-in. spacers already mounted on the engine.

On Pratt and Whitney engines remove the hold-down nuts of the engine's front section thrust bearing cover plate and remove the spacer washers. Install shield over studs with the opening for the feeder tube toward the top.

a. Install the fixed bracket for the feeder tube through the cutout in the shield and over the two upper studs near the top of the shield after spacers are in place.
b. Place the spacers supplied with the propeller over the studs and bolt the assembly down tight.
c. On Wright engines the same installation procedure applies, with the exception of the individual spacers. For Wright engines a ring spacer is provided which takes the place of the thrust bearing cover plate.
d. Install the feeder tube through the cutout in the shield and secure loosely to the fixed bracket.
e. After the propeller is mounted adjust the feeder tube sliding bracket until the feeder tube clears the slinger ring by 1/32 in.
f. Install the cover plate over the shield and safety-wire it in place.
g. Connect the de-icing fluid supply pipe to the 1/8-in. pipe connector.

Disassembly Instructions.—In general, the disassembly of the hydromatic propeller is the reverse of the assembly procedure.

Hub.—1. Before placing the hub assembly on the bench spindle, remove the barrel and spider packing lock ring, retaining ring, gland ring, and spacer. Remove the packing.

2. Place the unit on the assembly spindle.
3. Remove all barrel bolts.
4. Split the barrel halves about 0.010 in. at the parting line by driving aluminum wedges in the tapered reliefs at each blade bore.
5. Remove the blade packing nut locks, unscrew the nuts, and remove the packing.
6. Remove the front and rear barrel halves by wedging them apart as above and, if necessary, driving them off with a nonmetallic mallet.

Be careful not to mar or scratch the parting surfaces of the barrel. Sharp edges adjacent to blade oil seals should be carefully preserved.

7. Remove the blades, barrel supports, and the phenolic spider ring.
8. Remove the snap ring, retaining nut, front cone, oil seal, and oil seal washer from the spider.
9. Remove the shim plates, shims, gear segments, and spring packs from the blades.

Dome.—1. Remove the dome barrel oil seal.

2. Remove the six screws in the stop locating plate, and stops.
3. Remove the piston gasket nut lock, nut and gasket.
4. *Remove the four cam slot roller shaft lock screws in the rear side of the piston bosses.*
5. With the cam slot roller shaft puller, remove the four shafts from the piston.
6. Remove the piston.
7. Remove the cam slot rollers and bushings.
8. Remove the cam ball-bearing retaining nut from the front end of the rotating cam.
9. Tap the rotating cam out of the stationary cam and remove the bearings.

Distributor Valve.—1. If a breather tube is installed on the valve housing, remove its safety wire and unscrew the breather tube.

2. Remove the safety wire at the base of the spring housing and unscrew this housing.
3. Remove the distributor valve spring, washer, spring housing gasket, and distributor valve.

4. Remove the oil seal rings and expanders.
5. Unscrew the dome pressure relief valve ball plug and remove the sleeve and spring.
6. Remove the oil transfer plate and gasket from the base of the valve housing, being careful not to mar the sealing surfaces.

Note: This plate is a snug fit over two dowel bushings and must be pulled straight off the bushings. This may be assisted by tapping off with a rod inserted through the breather passages in the valve housing.

Propeller Inspection and Maintenance.—Visually inspect the hub and blades for damage that may have occurred during the previous flight.

Nicks and sharp dents on the leading edges, or gashes on the blade faces, are particularly dangerous as they greatly reduce the fatigue strength

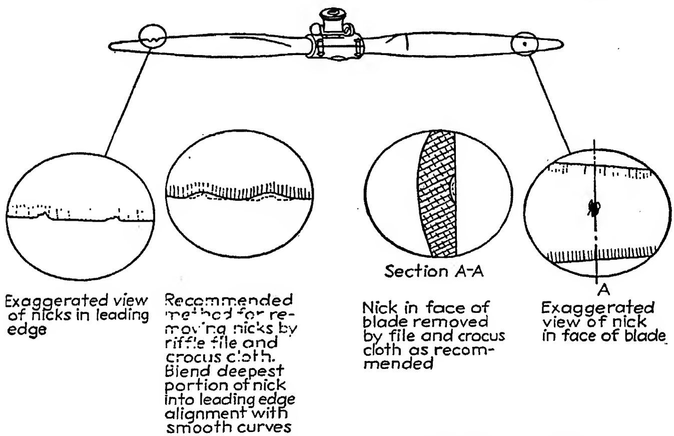


FIG. 39.—Recommended practice for repairing propeller blades.

at that particular point and failure may result unless they are removed promptly. (All mars on the surfaces of the blades are "stress raisers" and cause a stress concentration that may raise the stress beyond the endurance limit resulting in a fatigue failure.)

Sharp dents and nicks or gashes may be removed locally without reworking the entire blade surface (Fig. 39). A curved "riffle" file is recommended for use in removing the sharp base of the nick. Fine emery cloth or crocus should be used for polishing. Care should be taken in removing nicks from the blade face to be sure that the thickness is not reduced more than is necessary.

It is recommended, as an added safety precaution, that the surface, after removal of a nick, be etched, examined with a magnifying glass (to be sure that the nick is entirely removed and that a crack has not started), and then polished locally. Propellers having very severe nicks or gashes should be sent to an authorized service station or the factory for repair.

See that all lock wires and cotters are in place.

Check the cylinder assembly and external oil lines for oil leakage.

After the engine has been warmed up, operate the cockpit control and note the action of the propeller. The piston of a newly installed propeller should be checked for tightness after the first flight.

Lubricate as directed.

Clean the exposed portion of the piston with engine oil. This can be done with the propeller in the low-pitch position.

Propellers subjected to salt air or spray should be carefully washed with soap and fresh water or thoroughly cleaned with kerosene after flight. A coating of engine oil should then be applied for protection.

Overhaul Period.—The time between overhauls is left to the judgment of the operator. It depends largely upon the type of operation and maintenance given the propellers. In general propeller changes can coincide with engine changes, the overhaul period being the same for both.

Propellers should always be overhauled by competent men, who may be found at many of the principal airports. Some of the commercial air lines maintain stations for doing propeller repair work outside their own maintenance.

The amount of wear of some parts depends partly on the amount of power the propeller is required to absorb, partly on the plane-engine combination, and partly on the maintenance given to the propeller during and between overhauls.

Parts liable to need replacement are the cylinder head gasket, the inboard and outboard piston gaskets, the ball retainers in the cylinder bearing shaft thrust bearing assemblies, the front cone packing washer, the laminated shims, the counterweight bearing retainers, the oilite thrust washers, cotters, lock washers, etc. Although their condition may occasionally warrant reinstallation, it is usually best to replace these parts at overhaul.

Some wear and galling are to be expected on moving parts such as the counterweight bearing assemblies and the counterweight brackets. There may be some pickup of bronze from the blade bushings on the spider arms, particularly during the first 100 hr. while the propeller is being worn in. In general, blade bushings are good for approximately 1,000 hr., if not subjected to abnormal operating conditions. Other parts may also show wear. The blades are subject to pitting and erosion from water spray, cinders, rocks, etc. They must constantly be dressed down to eliminate sharp nicks and dents, as mentioned on page 475.

It is usually possible to straighten and repair aluminum alloy blades that have been bent or twisted. *Straightening must always be done by an approved repair station or the factory.* If the deformation is slight, the blades can be straightened cold. On the other hand if it is considerable, the blades must be annealed, reformed to approximate shape, heat-treated, then finished. An approved repair station has the necessary information to determine whether or not the blades should be returned to the factory.

Bushings may be removed and installed as follows: The blade bushing is pressed into the aluminum blade and held in place by two screws and two dowels. *This bushing should not be removed except by an authorized service station having complete equipment for this operation.*

Repairing Aluminum Propeller Blades.—The Hamilton Standard Propeller Co. makes several valuable suggestions regarding repair of detachable aluminum blades such as are used in their propellers. Many of these suggestions can be used on other blades. In some cases repairs are not approved except at the factory; in others one field repair is considered safe.

Special instructions have been issued regarding these blades. In general the following may be considered safe practice:

Bent blades are first inspected with a protractor similar to Fig. 40. This has marks 1 in. each side of the pivot. It is applied as in Fig. 41, so that

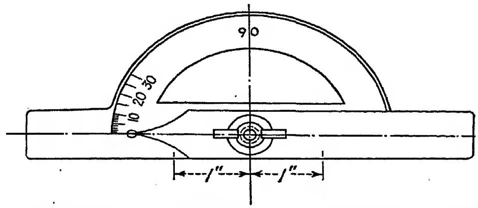


FIG. 40.—Protractor for checking the amount of bend in a propeller blade.

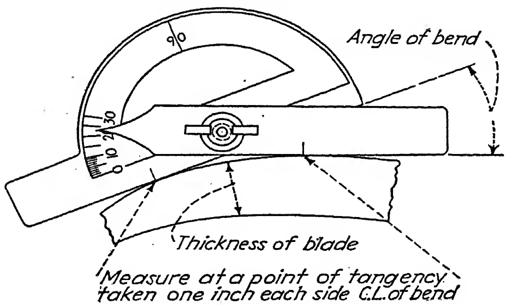


FIG. 41.—How the protractor is used.

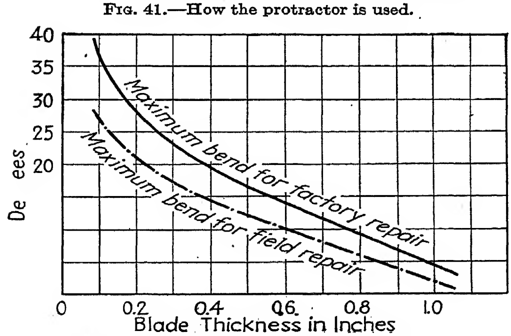


FIG. 42.—Chart showing when a blade can safely be straightened.

both marks are tangent to the bend, and the angle is then noted. The thickness of the blade is measured at the bend, as in Fig. 41.

Reference to Fig. 42 shows when the blade can be safely straightened cold. If the bend is over 20 deg., as shown in Fig. 41, the maximum thick-

ness that can be safely straightened in the field is 0.2 in. With factory facilities, however, the blade could be 0.35 in. thick, as shown by the solid line. If the bend is only 10 deg., the blade can be 0.6 in. thick and be safely repaired in the field, or over 0.75 in. if repairs are factory made.

Figure 43 shows how the blades are marked.

Blades may be cut down in both width and thickness as follows:

Inner ⅜	2½ %
Outer ⅛	5 %
Outer 12 in.	10 %
Outer 6 in.	May be modified as required

Blades Found to Be Repairable.—Blades found repairable should be etched from the tip to the shank section in caustic soda and cleaned in nitric acid; they should be polished after etching. The shank portion of the blade should be etched only at points *A* and *B* as indicated on Fig. 44. Care should be used to remove all traces of this local etch by polishing. Any suspected cracks in the blade section should also be given a local etch and again examined. Any cracks are cause for rejection.

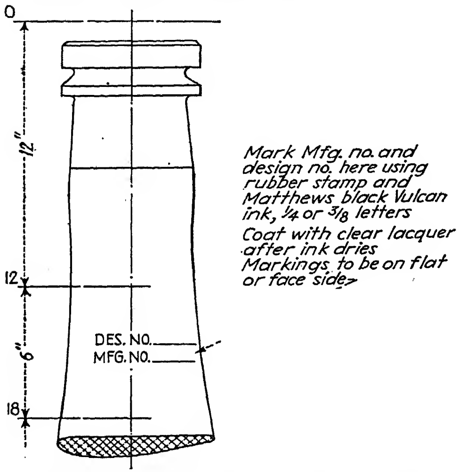


FIG. 43.—How and where the blades are marked.

Blades with bends in excess of the permissible amount shown in Fig. 42 should be annealed by holding them at 800°F. for ½ hr. and cooled with the furnace. The face alignment and angles may then be corrected. After straightening, the blades should be returned to the Aluminum Company for reheat-treatment.

Blades that are bent in edge alignment (if repairable) must be straightened while hot. This work can be done only at the factory.

Finishing Blades after Straightening.—Brinell the blade on the base to check the condition of heat-treatment. Brinell hardness must be 90 min. with 10-mm. ball and 500-kg. load. If the hardness is below 90, the blades must be reheat-treated.

Blades should be etched in caustic soda and cleaned in nitric acid. Do not etch the shank portion as this would affect the fit in the hub. Any suspected cracks should be given a local etch and again examined. Any cracks are cause for rejection. The date of etching and the repair station identification mark should be stamped on the base of the blade.

Select the blade from the propeller that will require the greatest modification and finish it up to smooth contour. The leading edge should be kept in accordance with the drawing section, using templates for this purpose.

The reworked blade section should conform to the template at the leading edge. The blade should be finished by polishing with a buffing wheel.

Modify the remaining blades of the propeller so that they are identical to the first blade within the tolerances given in the following table. Fit

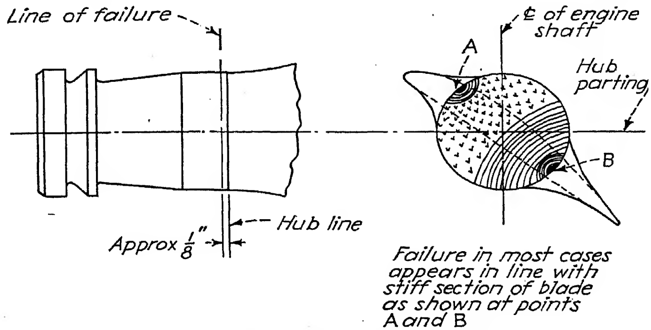


FIG. 44.—Location of typical blade-shank failure.

can be determined by use of a template that has been fitted to the first blade. The blades must be identical within the following tolerances:

Blade length, in.	1/16
Track, in.	1/16
Edge alignment, in.	1/16
Face alignment, in.	1/16

	Center of hub to 24-in. station	24 station to tip
Width of blade, in.	3/32	1/16
Thickness of blade, in.	3/64	3/64
Section shape shall conform to templates within, in.	1/32	1/32

	Center of hub to and including 18-in. station	24-in. and 30-in. stations	36-in. station to tip
Angle, deg.	1.0	0.5	0.2

Finish the blades by polishing with buffing wheel. Blade tips must be matched to a template made to fit the first blade.

Figure 45 shows how blades are straightened at the Naval Air Station at San Diego, Calif.

Propeller Balance.—It is necessary that the assemblies, to be balanced, be free from any oil except the thin coating applied during assembly for temporary lubrication; otherwise any balance results will be incorrect. Be sure the balancing stand is true and that there are no air currents near it.

Dome Assembly Balance.—1. Install the dome assembly on the bench balancing fixture (Fig. 46).

2. Insert the balancing arbor in the fixture extending through the breather hole in the front of the dome and place the assembly on the balancing stand.

3. The assembly may be balanced by the use of lead in the balancing holes provided in the base of the stationary cam under the stop locating plate.

Hub Assembly Balance (Including the Blades).—1. Insert the balancing arbor in the splined sleeve in the hub assembly and install the assembly on the balancing stand.

Note: The blades shall have been set at 25 deg. at the 42-in. station.

2. Check each blade in a horizontal position. The assembly should show no tendency to rotate.

3. Recheck the balance and the accuracy of the balancing stand by repeating 2 with the blades horizontal on the opposite side of the stand.

4. Balance may be obtained by inserting lead wool in the hollow barrel bolts on the light side of the assembly. In case this is not sufficient, the

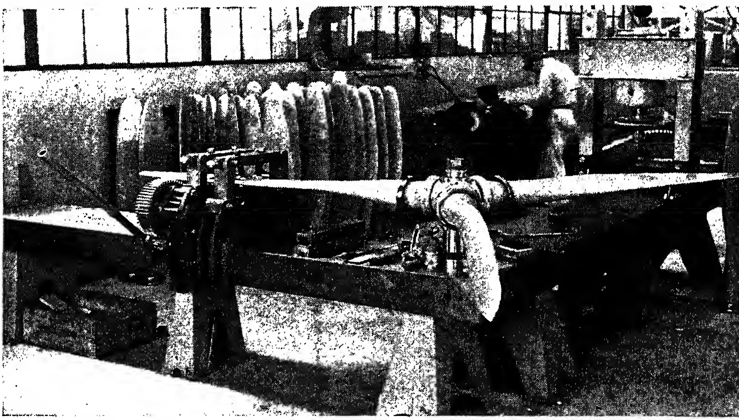


Fig. 45.—How blades are straightened at San Diego.

hub should be disassembled and balancing washers added to or removed from the blade plugs as necessary. The hub and blades should be reassembled, placed on the balancing stand, and the balance adjusted by lead wool in the barrel bolts. At least one and no more than five balancing washers should be used in each blade.

Hub Assembly (Including Dome Assembly).—1. With the splined sleeve in the hub assembly, install the dome unit on the hub assembly and set the blades to 25 deg. at the 42-in. station.

2. Insert an arbor through the splined sleeve so that one end protrudes through the breather hole in the dome.

For this balance, it is necessary that the arbor be reduced on each end to 1½ in. diameter so that one end will pass through the hole in the dome.

3. Install the assembly on the balancing stand and check the balance (items 2 and 3 under Hub Assembly Balance).

4. Final balance is obtained by readjustment of the lead in the barrel bolts.

5. Mark the dome and barrel to indicate the relative position after final balance.

Inspection.—Magnaflux.—Specifications covering Magnaflux inspection of all steel parts have been amended to include only those parts subjected to major stresses. It is considered unnecessary to Magnaflux minor unstressed parts.

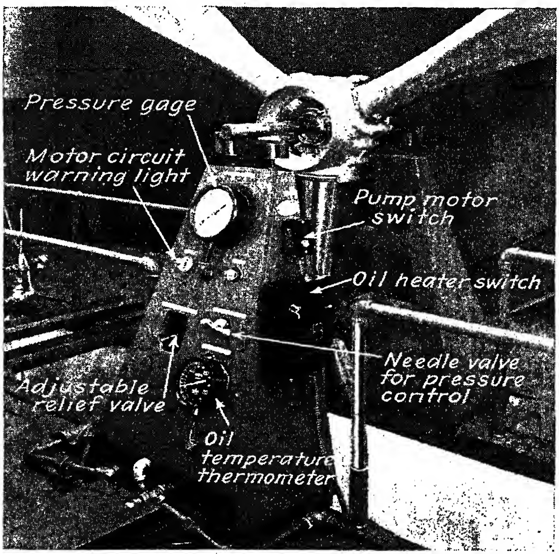


FIG. 46.—Balancing stand for propellers and test-control panel.

Only the following parts need be subjected to Magnaflux inspection:

Barrel—front half
Barrel—rear half
Bolt—barrel
Nut—barrel bolt
Spider
Washer (race)—thrust bearing, flat
Washer (race)—thrust bearing, beveled
Gear segment—blade
Cam—stationary
Cam—rotating
Roller—cam
Shaft—cam roller
Stop rings—positive high and low pitch
Shaft—drive gear (constant-speed control)
Gear—idler pump (constant-speed control)

Allowable Clearances
(Clearances are taken at 70°F.)

Clearance between	Clearance limit, new part	Replacement required when clearance exceeds
Blade bushing and spider arm	0.002L–0.0035L	0.006*L
Cam slot roller and cam slot	0.0055L–0.0105L	0.020L
Cam slot roller and bushing	0.001L –0.0035L	0.008L
Cam slot shaft and bushing	0.005L–0.0025L	0.005L
Cam slot shaft and piston	0.0005L–0.0025T	0.001L

* The letters L and T mean "loose" and "tight" by the amount shown.

Gear Pre-load.—The gear pre-load is determined as follows:

1. With the hub completely assembled and installed on the assembly post, *accurately* set each blade at 50 deg. at the 42-in. station with a protractor.

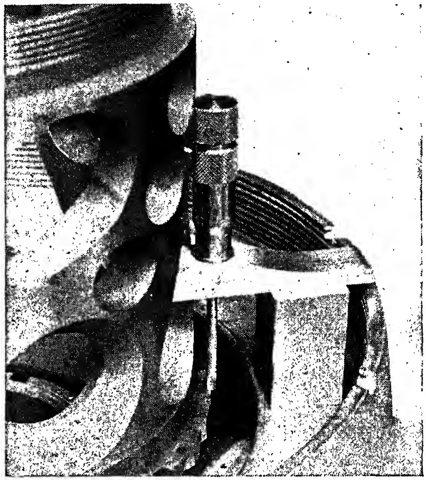


FIG. 47.—Determining pre-load on gears.

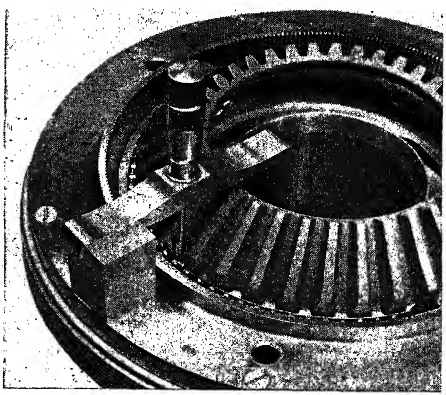


FIG. 48.—Checking gear pre-load by measurement.

2. Place the rotating cam in its proper position, resting by its weight alone, on the blade gear segments so that the gear teeth are properly meshed.

3. Using a depth gage with the aid of a size block, measure the distance from the upper surface of the barrel dome shelf to the cam ball-bearing race shoulder on the cam just above the gear teeth at three different points around the cam. Average these three readings (Fig. 47).

4. With the dome completely assembled, except for the positive high- and low-pitch stop rings, measure, with a depth gage and size block, the distance from the surface of the stop locating plate, which rests on the barrel dome shelf, to the rear surface of the inner race of the rear cam ball bearing (Fig. 48).

5. The pre-load is the difference between items 3 and 4 and should be 0.018 ± 0.005.

CURTISS ELECTRIC PROPELLER

The Curtiss electric propeller is operated from the airplane electrical power supply. The electrical energy for changing the propeller pitch

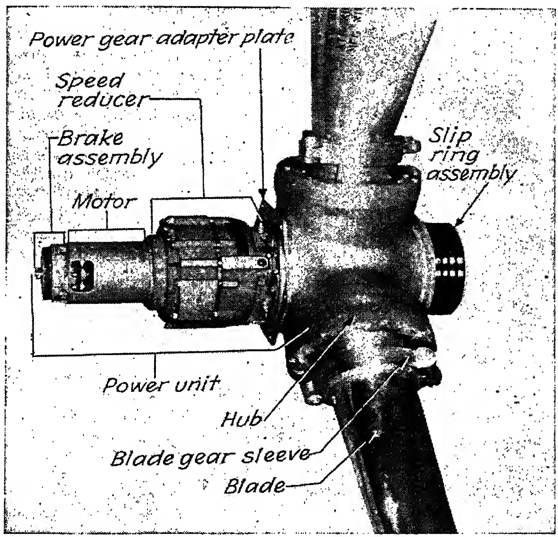


FIG. 49.—Power unit of Curtiss electric propeller.

passes through brushes mounted in a housing attached to the engine nose to slip rings mounted on the rear boss of the propeller hub, and thence to the pitch-changing motor through connector leads in the hub.

The electric pitch-changing motor controls the angle of blade setting through a two-stage planetary gear speed reducer which drives a power bevel gear. This gear meshes with bevel gears on the shank of each of the blades. Reversibility of pitch change is accomplished through a double field winding in the electric motor.

The propeller consists of aluminum alloy or hollow steel blades retained in a forged steel hub (Fig. 49). The root of the aluminum alloy blade is

clamped in a steel split sleeve which has a bevel gear machined on it. The steel blade has a bevel gear screwed into the root end and pinned in place. A stack of matched ball bearings of the angular contact type is placed on each blade assembly and is held in the hub barrel by a blade retaining nut. A grease seal is provided in the inner surface of the blade retaining nut to hold the lubricant within the hub.

The propeller power unit consists of the following subunits which are enclosed within the power unit covers, seen in Fig. 49.

Power Gear Assembly.—The power gear assembly consists of a bevel gear which meshes with the blade gears, an angular contact type ball bearing which takes the power gear thrust, and an adapter plate in which the power gear bearing is mounted.

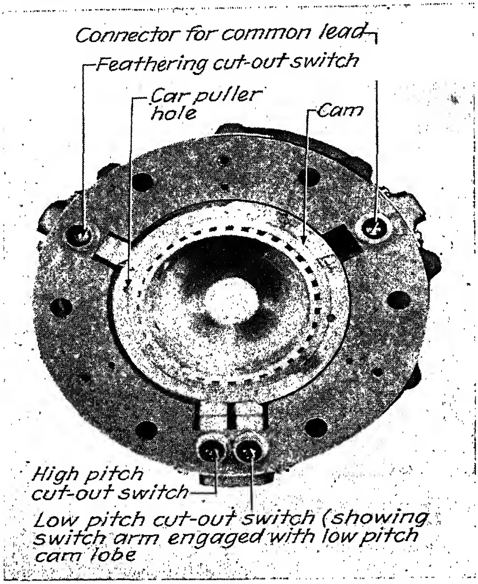


Fig. 50.—High- and low-limit cutout switches.

Speed Reducer.—The speed reducer includes a two-stage planetary-type gear speed reducer contained within aluminum alloy housings. The speed reducer is oil tight; so the gears and bearings operate continually in an oil bath.

The limit cutout switches are located at the hub end of the speed reducer. They limit the high and low pitch for the flight range and also stop the pitch change at the feather position. The high- and low-pitch cutout switches are effective while operating on both constant speed and manual selective control (Fig. 50). The feather cutout switch is effective only during the feather operation. Feathering is accomplished with a separate lead which by-passes the flight range high-pitch cutout.

A positive low limit stop is provided at the hub end of the speed reducer to prevent the propeller blades from flattening out in the event of a mechanical failure. This stop is set to take effect slightly below the electrical low-pitch cutout.

Electric Motor.—The electric pitch change motor is mounted to the front housing of the speed reducer. The motor armature is keyed to the driving pinion of the high-speed stage of the speed reducer. The motor is series wound and has a double field winding which makes it reversible. The leads are taken through holes in the speed reducer housings to the cutout switches.

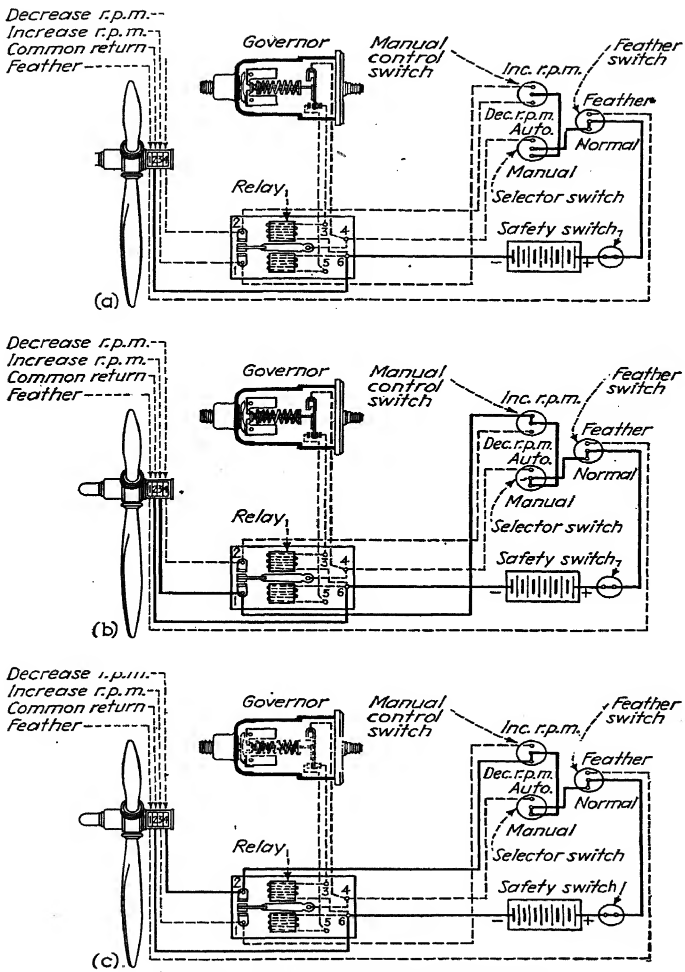


Fig. 51.—Wiring diagram for manual control.

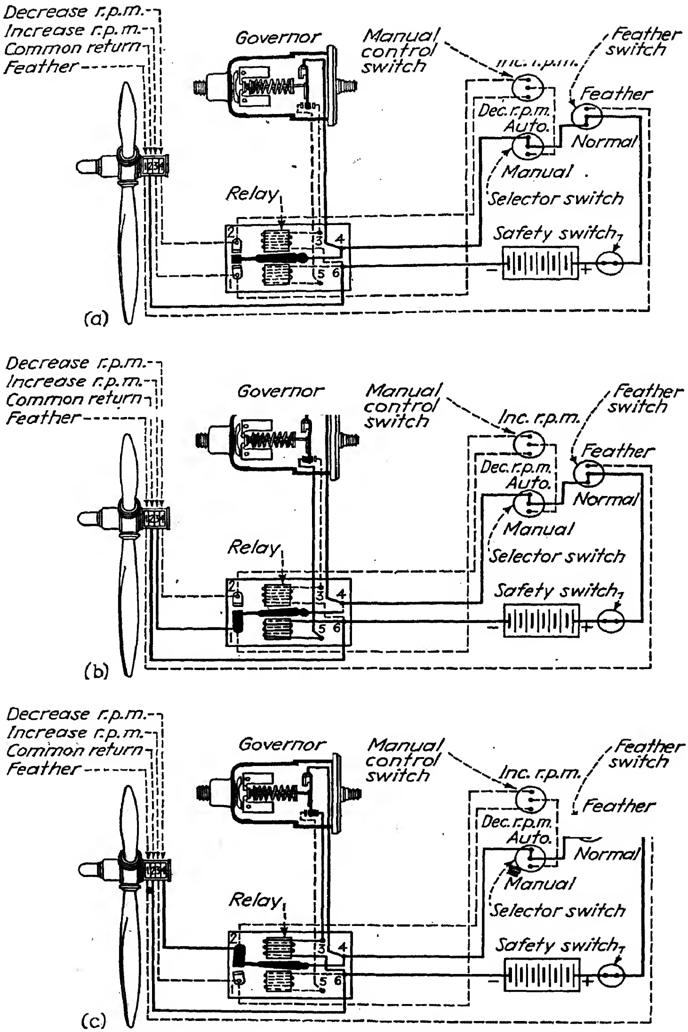


Fig. 52.—Wiring diagram for automatic control.

No Voltage Brake.—A brake is mounted on the front of the pitch change motor. It consists of a brake disk keyed to the armature shaft, a steel brake plate mounted behind the brake disk and held against it by coil springs, and a brake solenoid. The steel brake plate is pulled away from the disk by the solenoid, the coil of which is connected in series with the electric motor circuit. The purpose of this brake is to stop the rotation of the motor armature instantaneously when the pitch-changing current is cut off. The braking action is effective at all times when the pitch is not

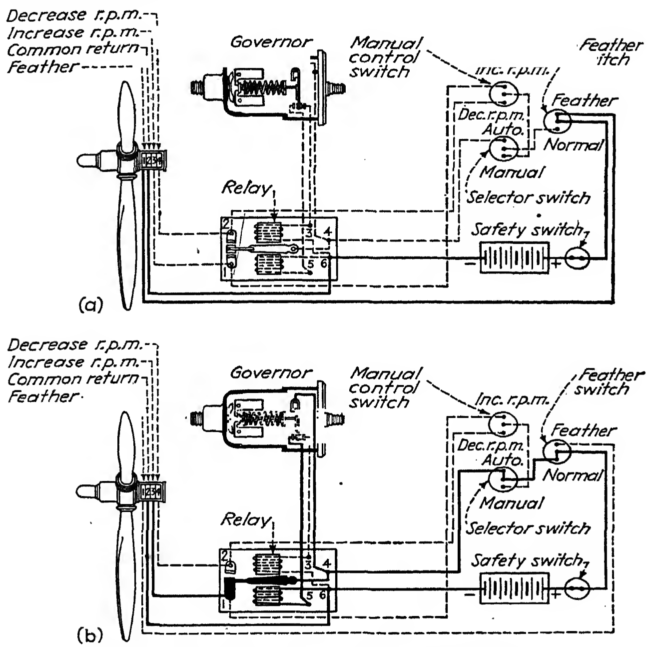


FIG. 53.—Wiring diagram and circuits for feathering control.

being changed; therefore, it also acts as a definite lock which prevents the pitch from being changed by the blade-twisting forces.

Brush Housing Assembly.—An aluminum alloy housing is attached to the nose section of the engine, providing a mounting for the slip ring brush assembly. The brush assembly, equipped with a disconnect plug for the wires, is held to the housing by two latches.

Propeller Controls.—Automatic constant-speed, manual selective, and feathering controls are provided. The constant-speed controls consist of a governor, a cockpit governor control, and a relay. The manual selective and feather controls consist of cockpit switches which, when operated, control the propeller pitch settings. Complete instructions for the propeller

controls are given on page 510. The current paths for manual control are shown in Fig. 51; Fig. 52 shows the automatic control wiring. The circuit for feathering control is seen in Fig. 53.

Installation of Propeller on Engine.—Each propeller is fully assembled, balanced, and adjusted at the factory. The entire propeller is tested for proper functioning prior to shipment. The blade retaining nuts are installed with a suitable antiseize compound, and the bearings are packed with Mobilgrease No. 2. The speed reducer contains 1 pt. of Curtiss speed reducer oil No. 1. The governor is fully lubricated, ready for installation.

For shipment, the power unit, and sometimes the propeller shaft nut, are removed from the hub. In handling, prior to and during the installation, care should be taken to avoid collection of dust and grit on the working

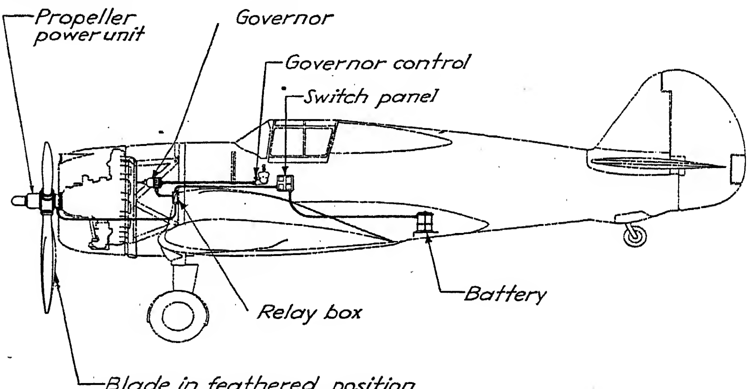


Fig. 54.—Typical Curtiss constant-speed installation on plane.

surfaces. Before installation, reference should be made to Figs. 49, 54, and 55.

Installation on Engine Shaft.—Check the thrust nut on the engine for tightness; clean the shaft threads, and splines thoroughly, removing all nicks, burrs, and galls from the shaft and the face of the thrust nut. Caution should be taken to note that the threads on the shaft are not burred or pulled.

Remove the nuts (and spacers or spacer ring if provided) from the brush housing mounting studs on the nose of the engine and place the brush housing on the studs. Replace the nuts, tightening and securing them. *Leave the brush assembly out of the housing unit until the propeller has been installed.*

Smooth all raised points on the rear cone. Clean the cone and place it on the shaft.

Place the propeller shaft locking adapter in the end of the shaft.

Thoroughly clean the threads and apply a coating of a mixture of 70 per cent white lead with 30 per cent castor or lard oil, or an approved antiseize compound, to the threads on the shaft and in the nut, and a light coating of engine lubricating oil on the splines.

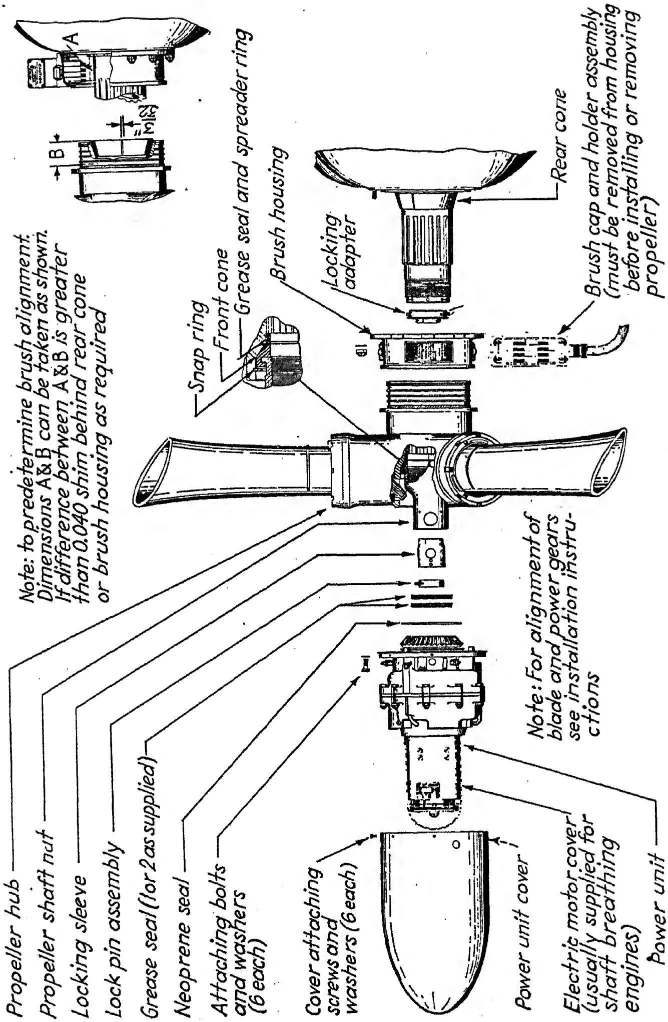


Fig. 55.—Details of propeller installation on engine.

To avoid damaging the propeller shaft threads while installing the propeller, it is desirable to use a thread protector. If a thread protector is used, proceed as follows:

1. Rotate the blade assemblies (decrease pitch) until the cutaway portion of the blade gear is forward and remove the snap ring, shaft nut, and front cone.
2. Screw the thread protector on the shaft; tighten it by hand only.
3. Locate the propeller on the shaft, being careful not to damage the shaft or rear cone seat. Slide the propeller back about halfway on the shaft.
4. Remove the thread protector.
5. Install the shaft nut, front cone, and snap ring.
6. Slide the propeller back until the nut touches the shaft end, then carefully start the nut on the threads and tighten it by hand.
7. Rotate the blade assemblies back into the normal flight range.

With a 3- or 3½-ft. bar through the nut apply a force of 250 to 300 lb. at the end of the bar to tighten the nut.

Apply a light coating of Prussian blue on the ends of the slip ring brushes and place them in the housing. Rotate the propeller back and forth slightly. Then remove the brush assembly and check the location of the brush contact on the slip rings as indicated by the Prussian blue. The brush track should be in the approximate center of the slip rings and not closer than 0.020 in. to the slip ring separators. If the brushes are not correctly aligned, it will be necessary to place one or more stainless-steel shims (furnished with the propellers) between the rear cone and thrust nut, or shim between the engine nose and brush housing. When the alignment is satisfactory, clean the brushes and install the brush assembly, locking the latches with safety pins.

Fit the locking tube to the adapter inside the propeller shaft nut so that a lock pin hole lines up with a hole in the nut. Place the lock pin assembly in position; then release the lock pin through both the locking sleeve and the propeller shaft nut, securing the same.

Power Unit Installation.—Two types of blade and power unit indexing systems are used: the first was used in the earlier model propellers and the second in the late models. They have, respectively, (1) index marks on the power gear and steel adapter plate, and on the blade gears; (2) index marks (Fig. 56) indicating a series of blade angles on the blade shanks just outside of the hub and a series of marks inside the power gear.

Instructions for the index marking system (1) are as follows:

Check the alignment of index marks on the power gear and on the steel adapter plate. To align these marks it will be necessary (1) to remove the steel mechanical low-stop plug, which is held in place by two 3⁄16-in. hexhead bolts just forward of the steel adapter plate. This *must* be done to eliminate the possibility of damaging the speed reducer when attempting to align the two index marks. (2) *After* the mechanical low-stop plug has been removed, the power gear may be rotated by introducing a 12-volt current into the pitch-change motor through the proper two contacts on the face of the adapter plate (Fig. 50).

Turn the blades in the hub until the index tooth on each blade gear lines up with the mark scribed on the inside of the hub.

Install felt grease seal over the propeller shaft.

Clean the contacts on the face of the hub and their mates in the power unit. Then place the power unit on the hub, aligning the contact points and bolt holes of the power unit and hub. Push the unit hard against the

hub so that the power gear meshes with the blade gears. Secure the unit tightly to the hub with the six attaching bolts and safety-wire them.

Completely fill the hub with Mobilgrease No. 2 by using a pressure gun on the three Zerk nipples located just forward of the front face of the hub. Check the speed reducer for the proper amount of lubricant as outlined in Maintenance Instructions, page 492.

Replace the mechanical low stop in the proper hole as indicated by the mark "O" stamped on the stop and housing and check the blade angles.

Install the speed reducer cover and safety-wire the screws.

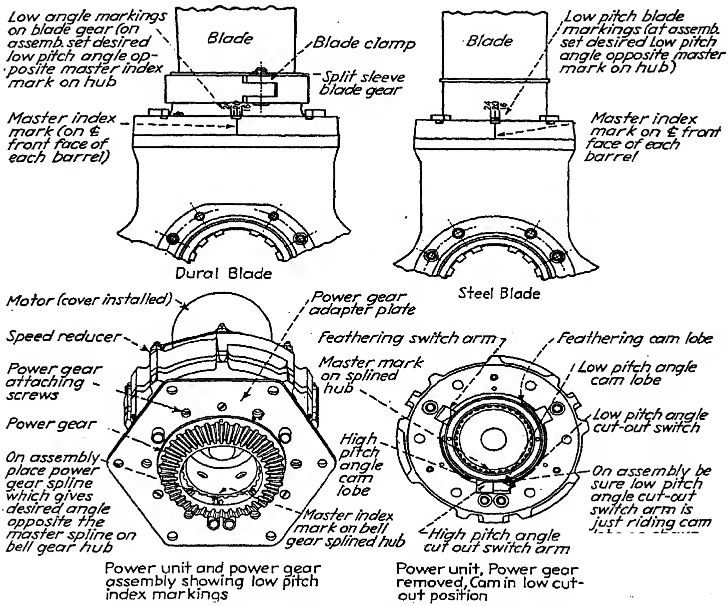


FIG. 56.—Method of index marking for Curtiss propellers.

Instructions for the index marking system (2) are as follows (Fig. 56). This system is used on later model propellers.

On the steel blade-retaining sleeves of aluminum alloy blade propellers and on the blade shanks of the steel blade propellers are acid-stamped lines which indicate pitch angles, when aligned with the index line on the front of each blade socket. The power unit splined shaft has a master or index spline which is indicated by a radial mark across its end. The power gear has marked spline spaces which are in steps of 1 deg. The angle indicated on the power gear nearest the master spline is the low pitch for which the propeller is adjusted. To install the power unit with this system, proceed as follows:

1. Remove the power gear and adapter plate from the power unit and see that the low limit cutout switch is just riding on the low limit cam lobe (Fig. 50). If it is necessary to run the power unit to locate the cam properly, proceed as previously outlined. Then replace the power gear, having the master spline in line with the mark indicating the desired low-pitch angle.

2. Align the marks on the hub and the marks on the blade shanks, indicating the desired low-pitch angle (same angle as power gear).

3. Check to be sure that the felt grease seal is on the propeller shaft and that the nut is satisfactorily locked. Then the bolt power unit in place as outlined.

4. Complete the installation by following the instructions previously given on page 488.

Maintenance and Lubrication Instructions. *Preflight Check.*—Safety switches must be in the "On" position. Engines may be started and warmed up with the propeller switches on "Manual" or "Automatic." To check the propeller "Manual" operation, open the throttle to turn the engine 1,000 or 1,200 r.p.m. Place the selector switch to "Manual" and hold down the "Decrease R.P.M." switch until a reduction in engine r.p.m. is noted; then hold to "Increase R.P.M." until the original engine r.p.m. is obtained. (When the engine r.p.m. ceases to increase, the propeller has reached its minimum pitch angle.) The ignition switches can be checked for individual magneto operation.

To check constant-speed operation, place the selector switch on "Automatic" and place the governor control lever or dial in "Take-off" position. Open the throttle until the engine turns approximately 1,600 to 1,800 r.p.m. and pull the governor control lever all the way back (if dial is used, turn it to low r.p.m.). If a reduction in r.p.m. is noted the control is operating. Return the control again to "Take-off" position.

Servicing at 25 Hr.—Thoroughly clean and visually inspect the hub and blade assemblies for damage or defects that may have occurred during the previous operation.

Check the operation of the limit switches by changing the pitch with the "Manual" switch in both directions until the limit switches operate (or cutout). On multiengine planes, place the feather switch to "Feather" position only long enough to determine that it will change pitch and then return it to "normal."

Lubricate the hub with Mobilgrease by using a pressure gun on the three Zerk fittings located on the speed reducer housing just forward of front hub face. The hub is to be completely filled.

Servicing at 50 Hr. (to Include Operations Outlined in 25-hr. Servicing).—Remove the brush cap and holder from the housing by unlatching the two latches and inspect the slip ring and brushes for wear. Clean oil and carbon dust from the brush holder and brushes; check the brushes and springs for smooth action in holder. Brushes that do not extend more than 3⁄16 in. beyond the holder should be replaced. Wipe the slip rings by holding a cloth against the rings while the propeller is rotated.

Installations on engines having propeller shaft crankcase breather only. Remove the power unit from the hub and clean the engine breather deposits from the spline shaft. Wipe clean and check the condition of the electric contacts on the face of the hub and in the speed reducer. Check the locking pin in the propeller shaft nut. Replace the power unit on the hub and secure.

Remove the electric motor cover and check the tightness of the motor retaining ring nut (must be tight). Check the general condition of the electric motor (terminals and wire connections, tightness and condition of brush riggings). By operating the pitch change manually (manual selective control) observe for satisfactory operation of the brake. Replace the motor cover and safety-wire.

Check the governor mounting bracket and the control system. If the governor drive adapter is provided with Zerk fitting, lubricate with Mobilgrease No. 2. Two strokes of the gun will be ample.

Check for excessive amounts of oil or grease in the switch compartment of the governor. This can be checked by loosening the screw through the slotted cover plate and moving the cover plate aside to permit inspection of the switch compartment.

Check the relay assembly. Remove the cover, examine all the electrical connections, and inspect the contact points for excessive pitting. Badly pitted points will be smoothed with a fine file or replaced. Replace the cover.

Servicing at 100 *Hr.* (*to Include Operations Outlined in* 25- *and* 50-*hr. Servicing*.—Remove the electrical power unit assembly and check the crankshaft nut for proper tightness.

Check the oil in the speed reducer. Rotate the propeller until the ⅛-in. pipe plug, located near the front of the housing, is approximately 20 deg. below the horizontal plane. The plug opening then indicates the proper oil level in the speed reducer housing. Normal capacity is 1 pt. **Caution.** Use only Curtiss speed reducer oil type No. 1.

Check the condition of the flexible drive shaft between the engine and the governor, and lubricate the shaft with Mobilgrease No. 2. After replacing the governor in the brackets, check the cockpit controls for proper adjustment.

Check the operations of the feathering circuit (on multiengined craft). With the safety switch "On," place the feather switch to the "Feather" position until the pitch changing stops at the feather position (slightly under 90-deg. pitch). Then place the switch back to "Normal," and with the selector switch in the "Automatic" position, the blades will again return to the normal angle. On installations not having a separate feather switch, it will be necessary to use manual control and the "Decrease RPM" switch for feathering. Feather return is accomplished by placing the selector switch back to "Automatic."

Check the brake clearance. The brake is mounted on the front end of the armature shaft. The clearance between the facings on the brake disk and on the steel brake plate should be 0.015 to 0.020 in. when the steel plate is pushed firmly against the brake coil housing which is mounted on the front end of the electric motor housing.

This clearance is adjusted by adding or removing shim laminations that are on the armature shaft behind the front brake disk. This disk can be readily removed by removing the castellated nut and using a puller; if a puller is not available, two screw drivers can be placed behind the steel brake plate to pry it free.

Removal and Disassembly of Propeller.—No specific time for propeller overhaul periods is recommended since the type of operation to which the propeller is subjected is the determining factor. However, in general, the propeller overhaul should be made to coincide with the engine overhaul periods.

Removal from Engine.—Unlatch the two latches that hold the slip ring brush assembly to the housing and remove the brush assembly. Removal of this assembly is necessary because damage would occur if the propeller were removed with the brushes in position.

Remove the de-icing supply tube from the slinger ring, if one is used.

Follow the reverse procedure as outlined in the Propeller Installation Instructions, page 488.

Power Gear Disassembly.—Unscrew the three flathead screws that hold the power gear adapter plate to the power unit and remove the power gear assembly from the power unit.

Note: Before pulling the power gear assembly off the power unit, mark or note the spline space opposite the marked spline on the power unit splined hub. This gives the angle at which the propeller is indexed and also the low-pitch angle of the propeller in case the stenciled marking on the propeller blade, which gives the low-pitch setting of the propeller, has been removed.

Remove the Bakelite-lined steel insulator bushings from the rear of the speed reducer housing.

Remove the snap rings and pull the power gear, bearing, and shims from the adapter plate, being careful not to damage the shims.

Magnetic Brake and Motor Disassembly.—Remove the motor cover.

Unscrew the ring nut that holds the motor to the front speed reducer housing.

Pick the insulation from around the four motor terminal screws at the rear of the speed reducer housing and remove the screws, thereby disconnecting the motor leads.

Unscrew the nut on the front end of the motor shaft, screw a puller in its place, and pull the motor from the speed reducer housing, at the same time working the leads out of the holes in the housing. *If a puller is not available, the motor can be worked from side to side slightly and pulled by hand at the same time.*

If it is found to be difficult to remove the motor as described, proceed as follows:

1. Remove the brake disk and plate.
2. Remove the motor housing at the same time working the electric leads out of the holes in the housing.
3. Remove the armature from the speed reducer by securely clamping the puller, having three jackscrews, around the armature. By evenly tightening the jackscrews, the armature will pull the speed reducer.

Unscrew the puller, then use a brake puller or two screw drivers behind the steel brake plate and pry the brake disk from the motor shaft. During this operation be careful not to damage the lining on either the brake disk or the brake plate.

Disconnect the solenoid leads, then remove the solenoid by removing the three attaching bolts.

Pull the armature from the motor housing.

Remove the brushes from the brush holder.

Speed Reducer Disassembly.—Remove the oil filler plug from the speed reducer housing and drain the oil.

Remove the nuts from the nine studs that hold the front and rear housings together.

Use a hammer and a brass, or wooden, block and tap the fixed ring gear until the ring gear, the front housing, and the internal gear assembly separate and are removed from the rear housing.

Lift the internal gearing out of the front housing. Disassemble it by removing the nuts from the end of the shaft and removing the gears, spiders, bearings, and spacers.

Rotate the low-speed bell gear until the cutout cam and mechanical stop screws are visible. Insert a screw driver through the breather holes in the rear housing and remove the screws holding the cam and those holding the mechanical stop segment. The screws holding the segment turn to the right when being removed and fall into the bell gear splined hub.

Screw two No. 10-32 bolts into the holes in the face of the cam and use them for pulling the cam.

Push the bell gear out of the rear housing, then remove the bearing, oil seal, and felt grease seal.

Removal of Cutout Switches.—Unscrew the terminal posts from the cutout switch assembly.

Pull out the clevis pins and remove the switch arms.

Pull the cutout switch assemblies from the rear housing. (The entire connector will come out of the housing when the terminal post is removed.)

Removal of Blades from Hub.—Place the hub assembly on a propeller checking table with the slip rings on the bottom.

Rotate each blade until the cutaway portion of each gear is toward the top.

Remove the snap ring from the groove in the front of the model and remove the propeller shaft nut and front cone. (On the model 5315-S propeller this cannot be done unless the blades are partly removed.)

Remove the lock from each blade nut, noting the locations in the hub and nut and remove each blade nut from its socket.

Pull each blade from its hub socket and place it on a clean assembly bench with the bearings overhanging the end of the bench.

Remove the shims from the bottom of the hub sockets, keeping them with their respective blade assemblies.

Disassembly of Aluminum Alloy Blades (Fig. 57).—Remove the nut from the blade gear clamp bolt and remove the clamp. If it is not a hinged clamp, screw it off the blade gear sleeve and slide it out on the blade, being careful not to nick the blade.

Using brass or aluminum blocks to cushion the blows, tap the bearings and spacer toward the blade tip until they are off the blade gear adapter shoulder. The two halves of the blade gear will then separate and the blade gear, spacer, bearing, clamp, and blade nut can be removed from the blade root.

Disassembly of Hollow Steel Blades (Fig. 57).—Tap the bearing stack toward the blade tip, using brass or aluminum blocks to cushion the blows, until the pin through the blade and blade gear is exposed.

Screw a puller into the tapped hole in the pin and pull the pin out of the assembly.

Unscrew the blade gear from the blade root. This can be done with a special wrench or by tapping the gear teeth with a brass bar and hammer. On a right-hand tractor blade the thread is right hand; on a left-hand tractor blade the thread is left hand.

Remove the bearings and nut from the blade root.

Disassembly of the Hub Assembly.—It is necessary to disassemble the hub assembly only when the slip rings need replacing. They must be turned on a lathe after replacement on the hub. It is not necessary to remove the slip rings for Magnaflux inspection of the hub.

Remove the safety wire and unscrew the six cap screws holding the slip ring to the hub.

Remove the slip ring assembly from the hub, taking care that the contact point extensions slide out of the hub without damage.

Unscrew the connector rods and withdraw them from the slip ring assembly.

Mark the slip rings so they can be reassembled in the proper order and position; then slide them off the Bakelite insulation tube.

Disassembly of the Brush Assembly.—Disconnect the wires from the brush block.

Remove the four screws that hold the brush block in the rubber mounting bushings in the cap, and pull the block out of the cap.

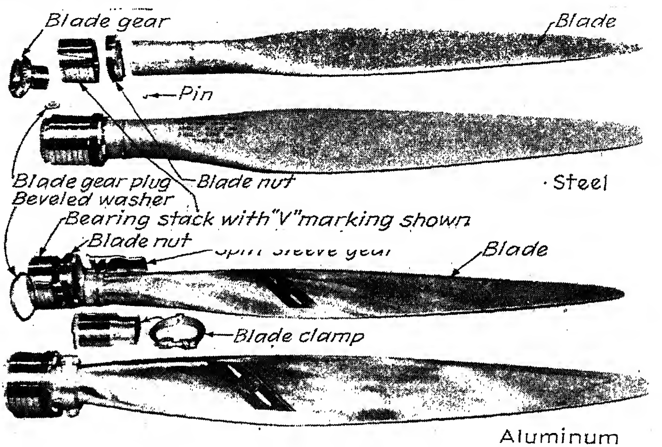


Fig. 57.—General construction of Curtiss steel and aluminum blades.

Remove the two countersunk brass screws that hold each brush connector block in place, freeing the brush pigtails.

Pull each brush out of its slot, being careful not to lose the brush spring.

Inspection and Parts Replacement.—After disassembly, all of the propeller parts should be inspected according to the following outline and the indicated repairs and replacements made. All ferrous parts should be inspected by the Magnaflux system if such equipment is available; if not, a very careful visual inspection will suffice. Clean all parts of the propeller with *clear* gasoline or kerosene before inspection.

Caution. Do not use *carbon tetrachloride* around any of the *carbon brushes* and do not use gasoline containing tetraethyl lead in cleaning the propeller parts.

Magnetic Brake.—Check the solenoid with an ohmmeter or a buzzer for an open circuit. Check for damaged coil leads.

If the facing on the brake plate or disk is glazed, remove the glaze with sandpaper or emery cloth; if it is badly worn, the facing should be replaced. Check the springs to be sure that they are not permanently compressed.

Inspect the brake disk cone, key, and keyway for cracks and looseness.

If the plating is worn thin on any of the parts, replate them.

Electric Motor.—Check the straightness of the armature shaft in a small lathe. Straighten it if necessary.

While the armature is on the lathe, the commutator can be refaced if necessary; if it is not necessary, clean and smooth it with sandpaper.

Check the armature circuits with a buzzer or light and visually inspect the windings for broken insulation. If the shellac on the armature is chipped, it may be reshellacked.

Inspect the keyway at one end of the armature shaft and the tang at the other end for signs of excessive wear. If they are damaged, the armature must be replaced.

Inspect the front motor bearing for wear and flat balls. If it is excessively worn or binds, it should be replaced.

If motor brushes protrude less than 3/8 in. from the brush holder because of wear or faulty springs, the worn and damaged parts should be replaced.

Check the field coil with a buzzer or ohmmeter.

Inspect the motor leads for broken or damaged insulation and splice on new leads if necessary.

Carefully inspect the motor ring nut, motor housing, and front speed reducer housing for signs of the motor having been loose in its mounting. If any of the parts are worn or damaged, they should be replaced. Check the locking key on the cover for looseness.

Speed Reducer.—Inspect all gears for worn or broken teeth. They should be Magnafluxed if such equipment is available.

Inspect all bearings for wear, flat balls, and smooth action. Replace all damaged or worn bearings. Check all bearings in their seats to be sure the races do not rotate in their seats.

Inspect the housing and spiders for cracks.

Carefully inspect the cam lobes and switch arms for excessive wear. Replace the worn parts.

If the switch contacts are corroded or pitted, smooth with a stone. If they are too badly damaged, replace them. If it is necessary to replace the contact spring or the contact itself, the whole contact assembly should be replaced. Replace the contact insulating bushings, if they are cracked or damaged.

If any of the plated steel parts are corroded, they should be cleaned and replated. *Be careful not to plate the bearing surfaces.*

Replace worn grease and oil seals, and all gaskets.

Power Gear Assembly.—Inspect the thrust bearing. If there are flat balls or worn races, the bearing should be replaced.

Magnaflux the power gear and the adapter plate if possible. If Magnaflux equipment is not available, carefully inspect for cracks.

Inspect the teeth and splines of the power gear for excessive wear.

Hub.—Magnaflux the hub if possible. Any small cracks or gashes that are deeper than 0.005 in. are a possible cause for replacement of the hub. It is advisable to consult the manufacturer when any such crack occurs.

Inspect the blade nut retaining threads for excessive wear, roughness, or nicks.

Inspect the cone seats with a cone gage. If metal has been picked up from the rear cone, it should be cleaned out and lapped with a fixture made for that purpose.

Check the splines for excessive wear.

If necessary, replate the hub. Coat the cone seats, threads, and inside of the blade sockets with beeswax when plating the hub to prevent plating these surfaces.

Slip Rings.—Inspect all slip rings for excessive wear. They can be smoothed and trued up after assembly to the hub by placing the hub on a lathe and turning them down. They should run true within the 0.003 in. full indicator reading. A piece of coarse cloth, such as the back of emery cloth, can be used for polishing the rings. The original thickness of the slip rings is 0.094 in. Therefore, care should be taken not to remove any more material than is necessary.

Inspect all Bakelite insulation. Any cracked or broken insulation should be replaced.

Inspect all connector rods for damaged threads and contact points for smoothness. The contact points can be smoothed with a stone. The threads on contact points and connector rods will be coated with litharge on assembly to prevent them from turning loose.

Brush Assembly.—Replace the brushes that have frayed or broken leads or that have been worn so that they do not protrude from the block at least 3⁄16 in.

Round off the corners of the brushes to approximately 18 in. radius.

Replace any brush springs that have been permanently compressed.

Propeller Shaft Attaching Parts.—Inspect the propeller shaft nut by the Magnaflux method if possible. Inspect for damaged, rough, or pulled threads.

If corrosion has occurred, replate the nut, protecting the face and flange that fits in the front cone groove, and the threads from plating.

Replace the felt seal if it has deteriorated.

Replace the locking tube if it is worn or damaged.

Inspect the propeller shaft adapter for excessive wear and make sure that the plungers are operating satisfactorily.

Aluminum Alloy Blades—Inspection and Repair.—Nicks and dents on the leading edge and face of the blades shall be blended into the blade contour with smooth curves by using a riffle file and crocus cloth. The maximum thickness of the blade shall not in any way be reduced. It is not necessary to take out all of a comparatively deep defect; it is sufficient to round out the edges and smooth the surface inside the defect and locally etch the spot to make certain there are no cracks. It is absolutely essential that no unnecessary removal of metal take place. If it is necessary to modify the tip of a blade, all blades of the propeller must be modified in a like manner. If it is necessary to reduce any blade section more than the following specified amounts to repair defects, the blade is unsafe and must not be flown.

Portion of Blade	
Shank	Within drawing limitations
Inner 3⁄8 in.	Within 2½ % of drawing dimensions
Outer 1⁄8 in.	Within 5 % of drawing dimensions
Outer 12 in.	Within 10 % of drawing dimensions
Outer 6 in.	May be modified as required

The manufacturer should be consulted if the condition of any blade is questionable.

Damaged blades should be repaired only by the manufacturer or a duly authorized agency. At overhaul, blades should be etched in a 20 per cent caustic soda solution and cleaned with a solution of 20 per cent nitric acid. Care should be taken not to etch the shank portion. Scratches and sus-

pected cracks should be given a local etch and then examined with a magnifying glass. The shank fillets and the front half of the face of the blade are the most critical portions. Also etch locally two areas about $1\frac{1}{2}$ in. in diameter on the shank portions in line with the leading and trailing edges just inside the outer edges of the blade gear sleeve. Examine with a magnifying glass for circumferential cracks. Any crack in this portion is cause for rejection. To etch locally a portion of the blade, clean off the area with fine sandpaper; apply the etching solution with a small swab. When the area is well darkened, wipe it off thoroughly with a clean damp cloth. Too much water tends to remove the solution from the defect and thereby spoil the check. If a crack or any other defect extending into the metal is present, it will appear as a dark line and small bubbles may be seen forming in the mark, with the aid of a magnifying glass.

Blades with bends not exceeding 20 deg. at 0.15 in. blade thickness to 0 deg. at 1.1 in. blade thickness may be cold-straightened by a duly authorized agency. Blades with bends in excess of this amount require heat-treatment and should be returned to the manufacturer for repair.

Blades bent in edge alignment should not be repaired by anyone except the manufacturer.

Check the radii at the bottoms of the retaining grooves to be sure that the retaining sleeve is not bearing on them. The sleeve should bear only on the flat shoulder.

If the blade has been anodized and the anodizing needs replacement, it may be suspended in the anodizing solution horizontally with the leading edge up. A double loop of $\frac{1}{8}$-in. aluminum wire resting in the lower retaining groove may support the shank, and another double loop approximately 1 ft. from the tip will support the remainder of the blade. The aluminum wires will act as conductors for the electric current.

Steel Blades.—Inspect the blades by the Magnaflux method if this equipment is available; if not, visually inspect for cracks. Any crack is cause for replacement.

Carefully clean and inspect the threads on the inside of the blade shank. After inspection, they should be coated with antiseize compound.

Check the locking pin hole for roundness. Ream for oversize pin with a bottoming reamer if out of round.

Inspect the outside surfaces of the shank for excessive wearing by the bearing races. This surface will normally show a radial line at the edge of each bearing race after several hundred hours of service, but they are of no consequence and do not progress with continued service.

If the chromium plating is badly worn from sand and small stones, the blades may be replated. *Care must be taken not to plate the threads.*

Check to see that the nut holding the balancing washer is tight.

Oil the surface of the blade with light engine oil.

Blade Retaining Parts.—Inspect the bearings for smooth, free operation and for signs of corrosion. The balls must be free from flat spots and the races free from brinelling marks and cracks. Any such defects will be cause for replacement. Wash the bearings carefully in clear gasoline and pack with Mobilgrease No. 2. If the replacement of a single bearing of a set becomes necessary, the entire set must be replaced. Bearings in each individual stack are matched for bore and outside diameter, and it will be necessary to return the stack to the manufacturer to ensure satisfactory matching of a replacement bearing.

Carefully inspect all steel parts by the Magnaflux method if possible.

Inspect the blade nut threads for roughness. Smooth any slight roughness; if it is deep, replace the nut.

If the blade gear teeth of the aluminum alloy blade are excessively worn, the gear may be rotated on the blade exactly two or three teeth and reindexed in that position. Make sure there is full tooth contact in the extreme high- and low-pitch settings. Also check for clearance of 1 to 2 deg. before the gear strikes the hub while in the extreme positions.

Strip, and replate with cadmium, all steel parts that show signs of rust or corrosion. *Do not plate the threads or polished bearing surfaces on the blade nut, or the finished bearing surfaces of the sleeve gear for the aluminum alloy blade assemblies.*

Individual parts from one blade assembly should be kept separate from those of another assembly. Interchanging these parts may result in difficulties during the final assembly of the blades to the hub.

Replace the leather grease seal in the blade nut if it is too pliable or if grease has been leaking from the socket in which it has been installed.

Assembly.—Care should be taken to assemble all interchangeable parts of the propeller, such as blades, blade gears, and blade bearings, in the same hub socket and in the same position from which they were disassembled in order not to disturb the balance of the propeller.

Aluminum Alloy Blades (Fig. 57).—Lay the blade on a clean assembly bench with the shank overhanging the edge of the bench.

Slip the blade clamp, the blade nut, the blade bearings, and the spacer well up on the shank of the blade in the order named. Be sure the outer beveled edge of the spacer is toward the bearing stack.

Notes: 1. The bearings are marked with a "V" and successively numbered. They should be arranged so the V points toward the tip of the blade and the numbers increase, from one to the highest number, from the tip inboard. It is absolutely necessary that bearings be correctly installed to avoid serious failure.

2. Each bearing stack bears a serial number on the outer race of each individual bearing (except in earlier model propellers) and it is essential that the bearings of a stack be always kept together.

Place the halves of the blade gear in position on the blade shank and slip the spacer and bearings on the machined bearing surface of the blade gear.

Place the clamp in position on the blade gear and tighten the bolt lightly.

Steel Blades (Fig. 57).—Lay the blade on a clean assembly bench with the shank overhanging the edge of the bench.

Slip the blade nut and bearings well up on the shank until they are past the locking pin hole. The same notes apply to the steel blade bearings as to the aluminum alloy blade bearings.

Screw the blade gear into place in the blade shank and tighten it with the tool provided or by tapping on the gear teeth with a brass bar until the locking pin holes in the gear and in the blade shank *exactly* line up.

Push the locking pin into place in the holes, being sure that the tapped hole in the pin is toward the outside so the puller can be screwed into it when it is desired to remove the pin, and slide the bearings down snugly against the blade gear.

Note: It is advisable to tape or otherwise wrap some kind of protective material around both the aluminum alloy and the steel blades when assembling to prevent scratching or otherwise damaging the blade.

Hub (Fig. 58).—Assemble the slip-rings and insulator rings on the insulator tube. If they are not assembled properly, the connector rod contacts will not be flush with the front face of the hub.

Install the labyrinth seal on the front end of the slip ring mounting tube and coat the joint with Copaltite, or some suitable sealing compound.

Install the six insulator bushings in the holes provided for the attaching screws.

Coat the threads on the connector rods with litharge and insert the connectors in their insulator bushings, screwing them into their corresponding slip rings.

Coat the rear face of the hub with Copaltite, or other suitable sealing compound, and press the slip ring assembly in place. Tighten and lock-wire the six attaching screws.

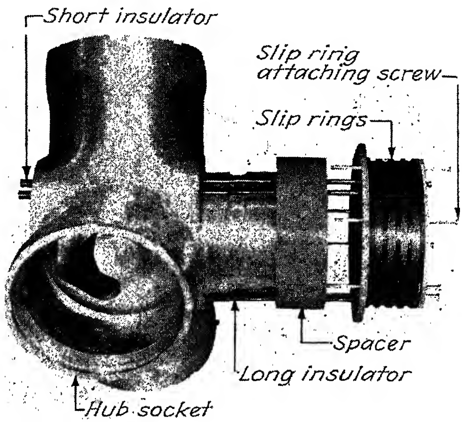


Fig. 58.—Assembling hub for three-blade propeller.

Mount the hub assembly on a lathe and true up the slip rings; they must run within 0.003 full indicator reading.

Check the contact points to be sure they are flush with the front face of the hub within ± 0.005 in. To adjust, add or remove shims directly under the head of the removable contact. On the final setting, coat the threads of the contact with litharge.

Blades in Hub.—On the C-5315-S propeller the front cone, propeller shaft nut, and snap ring must be placed in the hub before the blades are assembled in the hub. These parts may be installed at this time on all assemblies.

Place the hub on a propeller checking table or some other suitable spindle.

Coat the inside of the blade sockets with engine lubricating oil, and the threads on the blade nuts and in the barrel with antiseize compound (70 per cent white lead with 30 per cent lard oil is recommended).

Place a shim washer in the bottom of each blade socket having the radius side of the washer toward the center of the hub. On aluminum alloy blade

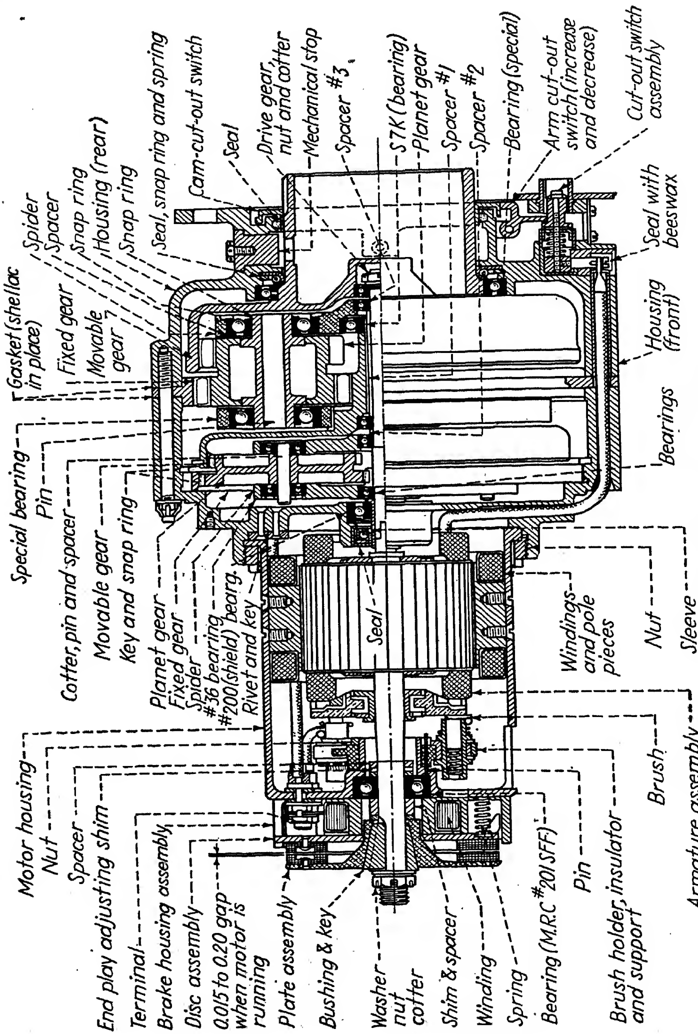


FIG. 59.—Curtiss propeller power unit assembly.

assemblies the thickness of this washer varies. The washers carry dash numbers −0, −2, −4, and −6 indicating their thickness and the blade gears are stamped .000, .002, .004, and .006 indicating backlash. Use a −0 washer with a .000 gear, −2 with .002, etc. On hollow steel blade assemblies, only a standard thickness shim washer is used.

Insert each blade assembly into its proper socket. Usually the blade with the lowest manufacturing number goes into socket 1; the next highest number goes into socket 2; the highest number goes into socket 3.

Screw each blade nut into the hub until one-half of the threads are engaged. Before tightening further make sure that the blade is pulled out as far as possible with all retaining shoulders securely seated. This is checked by sliding each blade assembly in and out several times, finally pulling it out sharply against the blade nut. With aluminum alloy blade assemblies, it is desirable to insert an aluminum or brass wedge between the end of the

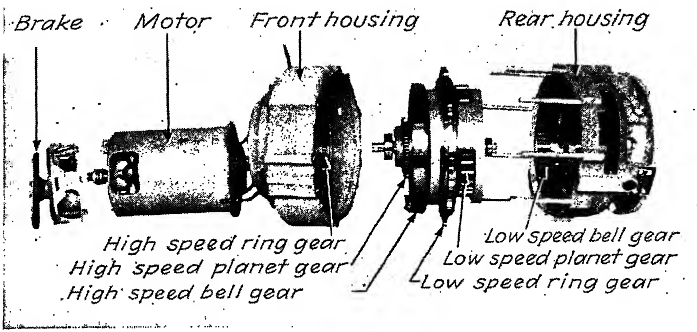


Fig. 60.—Parts of power unit assembly.

blade and the hub boss in the bottom of the blade socket and then tighten the blade nut as far as is possible by hand, using the blade nut wrench.

The blade nut is then backed off slightly and the wedge removed. The blade should be held out by hand while the blade nut is being tightened. Final tightening to preload the blade bearings is accomplished by sharply striking the end of the blade nut wrench (furnished with the propeller) with a 10-lb. brass hammer. It will be barely possible to rotate the blades by hand when properly preloaded. However, a check should be made with a wooden blade wrench to make sure the blades will rotate.

Speed Reducer (Figs. 59, 60, 61).—Install the leather oil seal, spring locking snap ring, and felt grease seal in the rear housing.

Place the mechanical stop segment in the breather section of the rear housing.

Press the low-speed bell gear bearing onto the shoulder on the bell gear, so that the thrust face of the outer race is away from the bell gear.

Press the bell gear into place in the rear housing, being careful to keep the oil seal spring expanded and to avoid damage to the leather oil seal. A tapered thin steel cylinder fitting over the splines may be used to guide the spline shaft into the oil seal.

Insert the two screws that hold the stop segment in place, from inside the bell gear, and tighten by inserting a screw driver through a breather hole in the housing. The screws should be staked in place.

Install the cutout cam by pressing it into place and installing the screws and lock washers through the breather holes in the housing. The cam will fit in only one position.

Press the oil seal in the front housing and stake it in place.

Install the high-speed fixed ring gear in the front housing if it has been removed.

Assemble the gears in the high- and low-speed spiders.

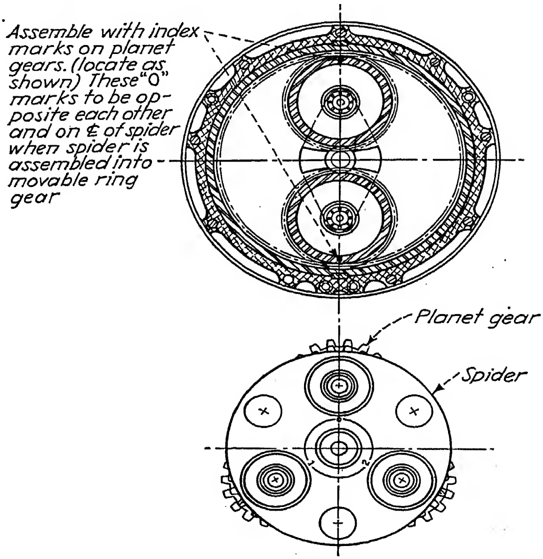


Fig. 61.—Method of indexing speed reducer gears.

Assemble the internal gearing, indexing it according to Fig. 61. Be sure that the index marks on the planet gears in each spider are as shown in Fig. 61 before meshing them with their sun gear. Be sure that the nut on the end of the shaft is cottered so as not to interfere with the bearing or housing.

Place a new gasket on the rear housing and drop the internal gearing in place in the housing. If they have been properly indexed, the planet gears will mesh with the low-speed bell gear without difficulty.

Place a new gasket on the studs and install the front housing, being careful to expand the oil seal while entering the drive shaft. Rotate the shaft with a screw driver in the drive slot while pressing the housing down on the studs so as to mesh the high-speed spider gears with the fixed high-speed ring gear.

Tighten the nuts in place on the nine studs and lock-wire them.

The high-speed end (electric motor end) of the speed reducer should be easily turned by a screw driver inserted in the motor drive shaft slot. If the unit binds, it should be disassembled and checked for improper assembly.

Install the limit switch assemblies, switch arms, and screw terminals in place. The contact points should extend 1/16 in. to 1/32 in. past the rear face of the power gear adapter plate when the cutout arms are in neutral.

Pour 1 pt. of Curtiss speed reducer oil No. 1 through the 1/8-in. pipe plug opening in the front housing and secure the plug.

Motor and Brake Assembly (Figs. 59 and 62).—Place the brushes and springs in the brush holder, making sure that the brush rigging is tight.

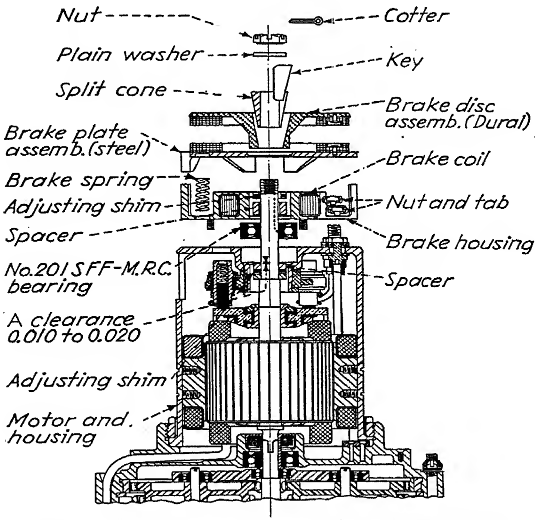


FIG. 62.—Motor and brake assembly showing end clearance.

Insert the armature tang in the speed reducer high-speed drive shaft slot. If the power gear has been removed, set the speed reducer housing on blocks so as to allow the low-speed drive gear free movement and tap the end of the armature shaft until it is tight in the speed reducer shaft and the speed reducer gearing is forced as far as it will go toward the low-speed end of the housing.

Slip the motor housing over the armature, feeding the motor leads through the holes in the speed reducer housing and tighten it securely in place with the motor ring nut. (Coat the threads with antiseize). This nut must be tight. If the motor is properly seated in the speed reducer housing, the bottom of the motor ring nut wrench slots will be flush with the top of the housing.

Install spacers and shims in place on the armature shaft and provide 0.010 to 0.020 in. between the top of the shims and spacers and the bottom of the bearing seat in the motor housing as indicated in *A*, Fig. 62. This is

necessary since it eventually controls the end clearance in the speed reducer assembly.

Be sure the locking pins through the brush holder and rigging nut are in place, then install the bearing in the front of the motor housing.

Secure the solenoid assembly in place on the front of the motor housing and attach to solenoid terminals on the motor housing, securing them.

Install the brake springs and steel brake plate. Place spacers and shims on the armature shaft and install the aluminum brake disk on the shaft and insert the key and cone. Install a plain washer and tighten the nut.

Check the brake clearance by holding the steel brake plate firmly against the solenoid. The clearance between the facings on the brake plate and the disk should be between 0.015 and 0.020 in. This clearance is adjusted by adding or removing shim laminations on the armature shaft directly behind the front brake disk.

Attach the motor leads to the cutout connector terminals using spring washers under the screw heads.

Seal the motor terminal connections in the rear housing with beeswax and install the motor cover. The motor cover must be tried with the locking key in each slot in the ring nut, until one is found that allows the screw holes in the motor cover to line up with the threaded holes in the motor housing.

Power Gear—Adapter Plate Assembly and Preload Adjustment.—Pack with Mobilgrease No. 2.

Slip the power gear laminated shim on the shoulder of the power gear.

Press the bearing into the adapter plate, being careful to have the thrust face of the outer race against the adapter. Lock it in place with a snap ring on an aluminum alloy blade propeller; on a steel blade propeller, the bearing does not have a snap ring.

Press the power gear into the bearing, then place the steel grease seal against the bearing, and snap the locking ring in its groove in the power gear. If the grease seal is not held snugly against the bearing, place shim laminations between it and the snap ring.

Check the gear preload with the propeller mounted on a checking table; line up the 20 deg. mark on the blade shanks with the mark on the blade sockets.

Mount the power gear unit on the hub and bolt it down tightly, using special short ⅜-in. bolts or the regular power unit attaching bolts with spacers under them.

Remove the bolts and check the clearance between the adapter plate and the face of the hub. It should be from 0.002 to 0.005 in.

If the clearance is not right, it can be adjusted by adding or removing laminations from the power gear shim between the gear and bearing.

Setting of Blade Gears and Blades in Their Proper Relation (Aluminum Alloy Blades).—The propeller is to be mounted on a checking table.

Set the center of the index tooth in line with the center line mark inside of the hub.

Make sure that the mechanical stop is removed; then run the power unit until the low-pitch cutout arm is just beginning to ride on the low-pitch cam (Fig. 50).

Place the power gear on the power unit having the 25-deg. mark in line with the master spline on the power unit.

Bolt the power unit to the hub and increase the pitch of the propeller a few degrees by connecting a battery to the slip rings, using a brush

assembly to avoid pitting the slip rings when the circuit arcs on being disconnected.

Run to low pitch.

This setting is 25 deg.; therefore, adjust the blade angles by loosening the clamps and rotating the blades in the blade gear sleeves to ±0.1 deg. Tighten and cotter-pin the blade clamp bolts. It is advisable to pull out on the blades while tightening the clamps to make sure they are out all the way in the blade gear sleeve. Clamp bolts are to be parallel to the 42-in. station on the flat face of the blade and with the head of the bolt toward the leading edge.

Remove the power unit, then set the power gear to the desired low-pitch angle by placing the power gear on the splined shaft having the desired low-pitch mark in line with the master spline.

Set the blades at the correct low angle by setting the proper marks on the blade shanks opposite the index marks on the blade sockets; then reassemble the power unit to the hub and check for correct angle settings.

On early types of propellers not having the angle settings indicated on the power gear, the following procedure will be used:

1. Set the center of the index tooth on the blade gear in line with the center line mark inside of the hub.

2. Bolt the adapter plate and gear assembly to the hub to hold the three blade gears in synchronization.

3. Adjust the blade angles by loosening the clamps and rotating the blades in the blade gear sleeves to exactly 25 deg. at the 42 deg.-in. station. Tighten the clamp bolts.

Adjustment of Angle Range (Fig. 56).—If it is desired to raise or lower the angle range use the following procedure:

Run the power unit until the low-limit switch cuts out.

Remove the power unit from the hub and the power gear assembly from the power unit. Replace the power gear having the desired low-pitch setting in line with the master spline. For example, if it is desired to change the low-pitch setting from 20 to 18 deg., replace the power gear with the 18-deg. mark opposite the master mark on the spline. It will be noticed that changing the setting in this manner raises or lowers all three settings (low, high, and feather) the same amount.

Line up the mark on each blade socket with a mark on each blade shank indicating the desired low setting (same angle as indicated on power gear).

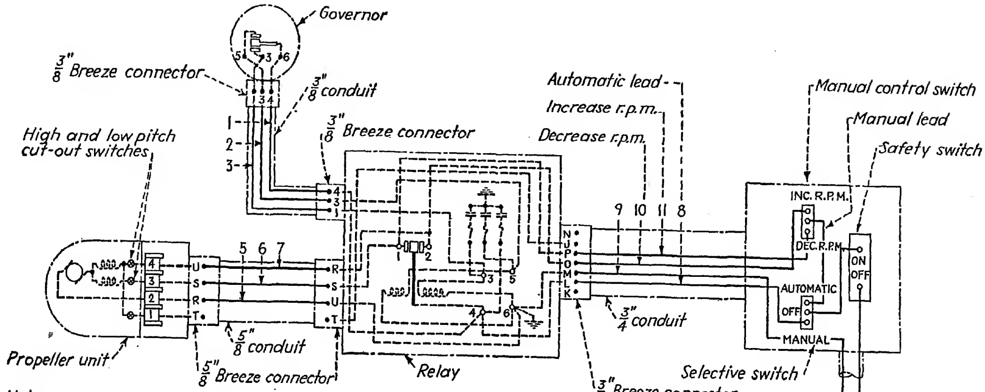
Replace the power unit on the hub.

Adjustment of pitch settings on early types of propellers, not having the angle settings indicated on the power gear, will be done in a similar manner as outlined. Movement of the power gear on the splines will increase or decrease the pitch setting approximately 14 deg. per spline depending upon the direction in which the gear is moved.

To adjust the high-pitch or feather settings independently, it will be necessary to replace the cutout cam with one having the desired settings. The original cam can be adjusted, however, by filing or welding the high-pitch or feather cam lobes to obtain the desired setting.

Note: The low-pitch cam lobe must not be changed under any conditions. The low-pitch mechanical stop is adjusted to be effective 1.5 deg. +0.5 deg. or −0.3 deg. of blade angle below the electrical low limit cutout angle.

Wiring diagrams for both single- and twin-engine planes are shown in Figs. 63 and 64. Wire charts showing the size in American wire gage and



Notes:
1- All propeller wires to be located in separate conduits excluding all other wires
2- This diagram for R.H. rotation propeller
3- Panel markings indicate direction of throw of toggle. terminals are opposite
4- Wire lengths in chart give a voltage drop of approximately 1.5 volts. All wiring should be calculated to keep voltage drop within this figure. This diagram is subject to change without notice

Code

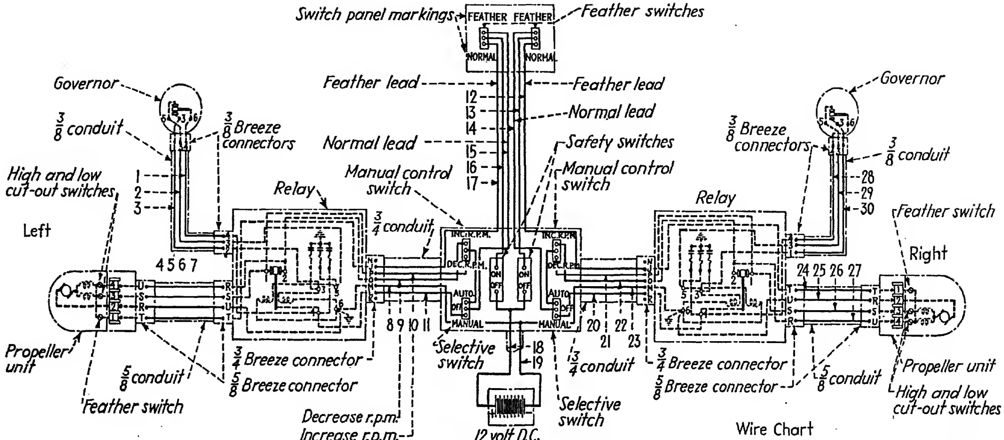
Indicate units

Indicate wires assembled in shop

Indicate wires assembled in field

WIRE CHART			
No.	Size A.W.G.	Length max. ft. estimate	Length actual
1	18	5	
2	18	5	
3	18	5	
5	10	10	
6	10	10	
7	10	10	
8	10	15	
9	10	15	
10	12	15	
11	12	15	
13	10	10	

FIG. 63.—Wiring diagram for single-engine propeller.



Wire Chart

No.	Size A.W.G.	Length max ft. estimate	Length max. ft. actual	No.	Size A.W.G.	Length max. ft. estimate	Length actual
1	18	5		16	10	15	
2	18	5		17	10	15	
3	18	5		18	6	10	
4	10	10		19	6	10	
5	10	10		20	10	15	
6	10	10		21	12	15	
7	10	10		22	12	15	
8	10	15		23	10	15	
9	12	15		24	10	10	
10	12	15		25	10	10	
11	10	15		26	10	10	
12	10	15		27	10	10	
13	10	15		28	18	5	
14	10	15		29	18	5	
15	10	15		30	18	5	

Notes:
1- All propeller wires to be to be located in separate conduits excluding all other wires
2- This diagram for R.H. rotation propellers
3- Panel markings indicate direction of throw of toggles; terminals are opposite
4- Wire lengths in chart give a voltage drop of approximate 1.5 volts, all wiring should be calculated to keep voltage drop within this figure. This diagram is subject to change without notice

Code
— - — - — Indicate units
- - - - - - - Indicate wires assembled in shop
———— Indicate wires assembled in field

Fig. 64.—Wiring diagram for twin-engine propellers.

the estimated length of each of the wires are given on each diagram. These wires allow for a drop of 1.5 volts, which should not be exceeded.

Governor Controls

The control system of the Curtiss electric propeller consists of a spring-loaded centrifugal type governor, relay, constant-speed cockpit control, and switches for automatic constant-speed, manual selective, and feathering control.

Governor.—The governor maintains the engine at a set constant speed by changing the propeller pitch angle to correct for varying conditions of operation such as engine power, airplane speed, and altitude. These governors are of the flexible shaft drive type, which is available with three types of r.p.m. adjustment controls, the flexible shaft control, sprocket control, and lever control.

The governor consists of a spindle and flyweight assembly driven at approximately engine speed through a flexible shaft and adapter from a suitable accessory drive on the engine. An adjustable coil spring counterbalances the flyweight forces and at the same time operates a three-position switch by means of an actuating rod. The three-position switch consists of a movable contact between two fixed contacts, all three having tungsten points. The movable contact is held against the increase r.p.m. contact by a preload on its bronze spring arm thereby closing the increase r.p.m. circuit. When the governor spindle speed is not enough to cause the flyweights to overcome the coil spring force, the actuating rod does not bear on the switch arm, allowing the movable contact to remain firmly in place against the increase r.p.m. contact (see *B*, Fig. 52).

As the spindle speed increases, the centrifugal force of the flyweights compresses the coil spring and at the same time, through the actuating rod, moves the movable contact switch arm away from the increase r.p.m. fixed contact, breaking the *increase* r.p.m. circuit. When the movable contact is not touching either of the fixed contacts, all circuits are open and the propeller remains at the pitch angle at which it is set at the moment of breaking contact (*A*, Fig. 52). If the r.p.m. increases further, the increased flyweight force will move the movable contact arm against the *decrease* r.p.m. fixed contact, closing the decrease r.p.m. circuit to the pitch change motor (*C*, Fig. 52). As the engine r.p.m. decreases, the movable contact arm moves away from the decrease r.p.m. contact, breaking the decrease r.p.m. circuit, (*A*, Fig. 52), causing the propeller pitch to again remain fixed until another variation in engine speed occurs. Figures 51 and 53 show manual and feathering control.

Relay.—The purpose of the relay is to control the high amperage current flowing to the pitch change motor by means of a 1/4-amp. control circuit. It consists of a switch arm pivoted between two fixed contacts and operated by two electromagnetic coils, one on either side of the arm. When one of the coils is energized the switch arm moves to that side closing one of the circuits to the pitch change motor; when the other coil is energized, the other circuit to the pitch change motor is closed causing the motor to rotate in the opposite direction.

A radio-frequency filter is placed in the relay circuit, if it is required to eliminate any possibility of radio interference due to the operation of the relay.

Two common types of cockpit controls are used to adjust the governor spring pressure and hence the governing r.p.m. They are the *lever quadrant*

type, used in single or multiengine planes with the sprocket or lever control type of governor and the *crank and dial type,* used only in single-engine planes with the flexible shaft, remote control type of governor.

Cockpit Control Switches.—These are of three types. A *control selector switch* allows the pilot to select the type of control he desires. This is a standard single-pole type switch having three positions: "Automatic," "Manual," and "Off."

An *increase RPM* and *decrease RPM switch* provides means of changing the propeller pitch when on manual selective control. The switch is a single-pole, three-position, momentary contact type, which closes the propeller circuit causing the blades to increase or decrease pitch as desired. Immediately upon releasing the switch it returns to the "Off" position, thereby opening the circuit.

A *feathering switch,* used only on multiengine ships, is designed to break the normal propeller circuit and at the same time to complete the "Feather" circuit, causing the propeller to go to the feather setting (Fig. 53). This is a standard single-pole two-position switch.

A *safety switch,* used in most installations as a type of circuit protection, is the thermal circuit-breaker type. It is used as a line switch and also to protect the propeller circuit against an overload. If this switch is opened by an overload, it may readily be closed by throwing the switch to full "Off" position and then throwing it to the full "On" position. When the switch opens due to overload, the handle moves only half of its normal travel.

Installation Requirements.—A typical control installation for a single-engine airplane is shown schematically in Fig. 54, page 488. General requirements for the typical installation are outlined below although it is recommended that the manufacturer be consulted before any new installation is attempted.

Wiring.—Diagrams are shown in Figs. 63 and 64. 1. It is recommended that all propeller wiring be carried in separate conduits from the other airplane wiring.

2. All motor circuit wiring must be of sufficient size to limit the voltage drop to 1.2 volts when the motor load is 20 amp. American wire gage No. 10 or 12 is usually satisfactory.

3. All relay solenoid and governor circuit wiring carries only ¼ amp.; therefore, American wire gage No. 18 wire will be satisfactory for these circuits.

4. All terminal lugs must be firmly soldered to the ends of the wires. Care must be taken to prevent terminals from touching other terminals, causing short circuits. Wedg-on, or an equivalent type of terminal, may be used.

Governor Installation.—The governor should be mounted in an accessible location in the engine compartment in a clamp type bracket. If the engine mount is shock mounted to the fire wall, the governor bracket should preferably be supported from the fire wall rather than the engine mount in order to minimize the effect on governor control setting of engine mount deflection. The governor location should be such that the axis is in line with the selected accessory drive so that the governor drive shaft connecting the governor drive adapter and the governor may be straight and without bends.

Relay Installation.—The relay should be mounted in the engine compartment in an accessible location preferably on the fire wall.

Installation.—The procedure used to install the governor is as follows:

Table 1.—Approximate Governor R.P.M. Settings

Governor, No.	Range, r.p.m.	No. of turns from low r.p.m., limit stop	R.p.m. of governor	Governor No.	Range, r.p.m.	No. of turns from low r.p.m., limit stop	R.p.m. of governor
88200	1,400–2,780	0	1,400	89800	1,255–2,720	0	1,255
		2⅜	1,500			2	1,500
		15¼	2,000			6¾	2,000
		24⅛	2,500			10½	2,500
		29¼	2,780			11¾	2,720
89400	1,400–2,600	0	1,400	89999	1,360–2,900	0	1,360
		1	1,500			3	1,500
		7½	2,000			16½	2,000
		11	2,500			26	2,500
		13	2,600			30	2,900
89600	1,280–2,760	0	1,280	100200-D	1,330–2,900	0	1,330
		1¾	1,500			3	1,500
		6⅛	2,000			17	2,000
		9⅘	2,500			26	2,500
		11½	2,760			33	2,900
89650	1,293–2,600	0	1,293	100300	1,380–2,900	0	1,380
		3¼	1,500			1	1,500
		15¾	2,000			6	2,000
		28¾	2,500			10	2,500
		30	2,600			12	2,900
89700	1,324–2,790	0	1,324				
		1½	1,500				
		6⅙	2,000				
		9¾	2,500				
		11½	2,790				

Notes: 1. These are average values with the gap set from 0.020 to 0.035. The sensitivity of the governor varies proportionally with the width of the gap. If a calibration of the governor being installed is at hand, use it in place of this table. On the later type of governors, the number of turns of the spring pressure adjusting screw from the low r.p.m. stop to the take-off r.p.m. position is stamped on the governor plate.

2. The spring pressure adjusting screw turns slightly harder in the increase r.p.m. direction.

Flexible Shaft Control Type Governor.—1. Rotate the governor spring pressure adjusting screw in the low r.p.m. direction (the direction in which it rotates easier) until the limit of its adjustment is reached.

2. Rotate the governor spring pressure adjusting screw the proper number of turns from the low r.p.m. stop to obtain the take-off r.p.m. setting. The number of turns is stamped on the governor data plate on the side of the governor.

Note: For the older type of governor not having the governor data plate, the approximate number of turns may be obtained from Table 1.

3. Install the governor in its mounting bracket in the engine compartment and connect the governor drive shaft and governor drive adapter.

4. Set the cockpit governor control dial at take-off and attach the flexible control shaft to the governor.

5. Any error between the dial graduations and the tachometer may be corrected by disconnecting the flexible control shaft from the control in the cockpit and setting the dial to read the same as the tachometer, then reconnecting the control shaft.

Lever Control Type Governor.—1. Set the governor lever at take-off r.p.m. by aligning the stamped mark on the lever boss and on the lever case.

2. Set the cockpit governor control at the take-off r.p.m. setting (full forward position).

3. Install the governor in the governor mounting bracket in the engine compartment and connect the governor drive shaft and drive adapter.

4. Connect the push-pull rod so that *exactly* take-off r.p.m. is obtained when the cockpit control is in the forward position.

Sprocket Control Type Governor.—1. Set the governor sprocket at take-off r.p.m. by rotating the sprocket in the increase r.p.m. direction (the direction in which it rotates harder) for three-quarters of a turn from the low r.p.m. stop plus the additional amount necessary to align the stamped marks on the sprocket and case.

2. Set the cockpit governor control at the take-off r.p.m. setting (full forward position).

3. Install the governor mounting bracket in the engine compartment and connect the governor drive shaft and drive adapter.

4. Connect the governor control chain to the governor sprocket.

5. Adjust the control cables so that *exactly* take-off r.p.m. is obtained when the cockpit control is in the forward position.

Final Check.—A check should be made without running the engine to determine that all circuits are properly made. For the manual check,

1. Place the safety switch to "On" position and the selector switch to "Manual." Hold the r.p.m. switch to "Decrease RPM" and note that the propeller blades increase pitch.

2. Hold to "Increase RPM" and note that the blades decrease their pitch.

3. Check the blade angles in low-pitch and high-pitch position for correct settings. On multiengine installation, the feather angle should also be checked.

For the automatic check,

1. Place the safety switch to "On" and the selector switch to "Automatic."

2. Move the center contact in the governor (access obtained through slotted plate on side of governor) toward the control end of the governor and note that the propeller pitch increases. Caution must be exercised to avoid damage to governor contact points.

3. Release the contact and the pitch will decrease.

For an outline of the preflight test see Operation on page 517.

Disassembly.—At propeller overhaul periods it is advisable to disassemble the governor, inspect the parts, and repair or replace those that are defective. The governor control and switch assemblies do not ordinarily require disassembly. The normal 50-hr. inspection is sufficient to keep these parts in satisfactory condition.

Flexible Governor Drive Shaft.—Remove the flexible drive shaft and adapter from the engine and the governor case. Pull the shaft from casing. Disassemble the adapter.

Governor.—Be sure that the cockpit governor control is set at take-off r.p.m.

Note: On all governors not having the number of turns from the low r.p.m. stop to take-off r.p.m. stamped on the data plate, the following precautions will simplify the procedure of setting the governor for take-off r.p.m. prior to installation in airplane.

1. *On flexible shaft control,* disconnect the flexible shaft *being sure not to move the spring pressure adjusting screw.*

2. *On lever control,* mark the housing and lever so that the lever position can be checked when the governor is removed from the airplane; then remove

the push-pull rod from the lever. On later governors this mark is already made.

3. *On sprocket control,* mark the sprocket and housing so that the sprocket position can be checked when the governor is removed from the airplane; then remove the chain from the sprocket. On later governors this mark is already made.

Disconnect the Breeze plug.

Remove the governor from the airplane.

Remove the governor end plate and rotate the spring pressure adjusting screw to the low r.p.m. stop. *Note:* If the governor does not have the number of turns of the spring pressure adjusting screw from take-off r.p.m. to low r.p.m. stop stamped on the data plate, caution must be used when removing the end plate so as not to change the adjusting screw from the take-off r.p.m. position. *Count the number of turns of the adjusting screw from take-off setting to the low r.p.m. stop.* During the reassembly of the governor, the adjusting screw can be reset to the exact take-off r.p.m. by turning the screw the *same number of turns* from the low r.p.m. stop.

Remove the flyweight case from the switch case by removing the holding screws.

Remove the plunger from its guide, being very careful to avoid bending the rod.

Remove the governor spring.

Remove the spring block from its guide by turning the spring pressure adjusting screw.

If the switch contact points need replacing, the entire switch assembly may be disassembled by removing the holding screws. This is necessary only when the contact points need replacing.

Press the flyweight spindle assembly from the flyweight case with the use of a brass or aluminum drift pin held against the drive shaft connector.

Press the bearings and spacer from the spindle.

Remove the flyweights from the spindle by removing the pivot pins.

Relay.—Disconnect the Breeze plug or wire connections from the relay and remove the relay from the airplane.

Inspection. *Flexible Drive Shaft.*—Inspect the flexible drive shaft for wear. Replace it, if it is badly worn. Check the governor drive gears, shafts, and adapter oil seal, if any. Replace parts that are excessively worn.

Governor.—Inspect the spindle bearings for rough or broken balls and excessive wear.

Inspect the pivot pins and pin holes in the spindle for wear. If the flyweights move sidewise on the pins, the worn parts should be replaced.

Inspect the plunger rod for smoothness, taking particular care to note the portions of the rod that slide in the bushings. In some instances chips may be pushed up when the bushings are installed in the guide, and cause the plunger rod to bind. Rough or worn spots on the plunger rod are an indication of this condition. Inspect the plunger rod for straightness in a small lathe.

Inspect the plunger rod bearing and bearing cap for excessive wear or seizure.

Inspect the threads on the spring pressure adjusting screw and run the spring back and forth on the guide with the screw to be sure the spring pressure adjusting mechanism operates smoothly.

Inspect the spring pressure adjusting screw mechanism.

If the switch contacts are pitted, smooth them with a stone.

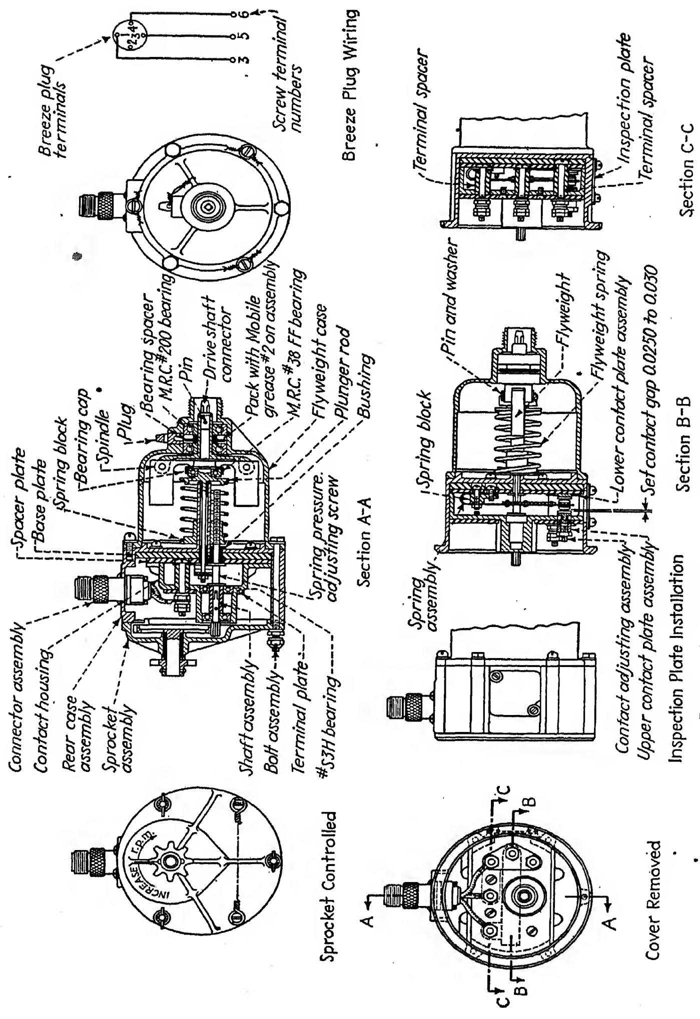


FIG. 65.—Details of sprocket-controlled governor assembly.

Inspect the wire connections to the switch terminals and Breeze plug.

On the flexible shaft control type, inspect the bearing and coupling for wear, and the adapter to see that it is screwed firmly into place.

On lever and sprocket types, inspect the bearings, gears, and pinion for wear and ease of operation.

Relay.—Inspect the relay contacts for excessive pitting; smooth with a fine file or a stone; replace if necessary.

Check all circuits through the relay with a bell or buzzer.

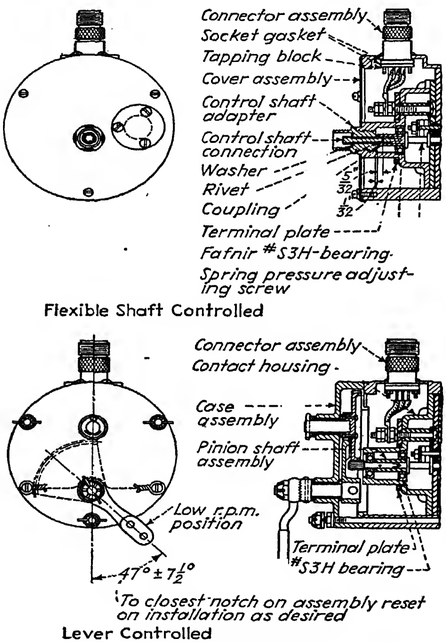


FIG. 66.—Flexible shaft and lever controls.

Check the electric terminals to be sure that good contact is being made.

Check the condensers for short or open circuits.

Assembly. *Governor.*—Assembly of the governor with three methods of control is shown in Figs. 65 and 66. Press the spindle bearings and the spacer into place on the spindle.

Assemble the flyweights to the spindles with the flyweight pins, washers, and steel cotter keys.

Press the spindle assembly into the flyweight housing.

If the spring pressure adjusting screw has been removed, replace it in its bushing.

Secure the switch assembly to the base plate. When properly assembled, the contact spring arm should give a pressure of not less than $\frac{1}{10}$ lb. on the increase r.p.m. contact when the plunger rod is entirely withdrawn. The maximum pressure is limited only by the spring arm itself. In order to assure firm contact with the *decrease* r.p.m. contact and at the same time prevent the reverse bend from introducing a permanent set in the spring when the plunger rod overtravels, the contact spring arm should be adjusted so that the contact will just be made with the decrease r.p.m. contact when the gap is set between $\frac{3}{32}$ and $\frac{1}{8}$ in. and the plunger rod is pushed in the guide as far as it will go. The final gap should be set between 0.025 and 0.030 in. unless otherwise specified.

Install the spring block on its guide and run it against rear case with the spring pressure adjusting screw.

Place the governor spring over the guide and against the spring block. Install the plunger rod. *Be extremely careful to avoid bending the plunger rod. This is important.*

Be sure that the spring tension is fully released. Place the governor in a vertical position, then press the flyweight case straight down on the rear case to avoid bending the plunger rod, and secure the two cases together.

If a transitorque, tachometer test rig, or any other testing rig that gives and indicates variable r.p.m. settings is available, the governor should be checked, before installing it in the airplane, according to the following outline:

1. Determine the exact governor drive ratio.
2. Rotate the governor spindle at take-off r.p.m. or its equivalent if the ratio is not exactly engine speed. If a tachometer test rig is used, be sure the spindle is rotating at the same speed as the tachometer reading. (Most tachometers rotate at one-half engine speed; therefore, a tachometer test rig would be geared down 2 to 1. If a tachometer test rig is used, it will probably be necessary to drive the governor through a 1 to 2 adapter.)
3. Attach a small crank to the spring pressure adjusting screw.
4. Run the spring pressure adjusting screw back against the low r.p.m. stop. (The spring pressure adjusting screw turns easier in the decrease r.p.m. direction.)
5. Set the rig so that it runs at the desired take-off r.p.m., then turn the crank on the spring pressure adjusting screw until the governor switch arm is at equilibrium between the two contacts. Be sure to count the *exact* number of turns between the low r.p.m. stop and the take-off r.p.m. setting. This is the setting used when installing the governor in the airplane. On later type governors having a data plate, the number of turns from the low r.p.m. stop is indicated on the plate.
6. It is advisable at this time to test the governor at several other r.p.m. settings and note its sensitivity and accuracy of correction.
7. When installing the lever and sprocket-type rear covers, set the mark on the lever or on the sprocket so it lines up with the mark on the case when the screw is turned to the take-off setting.

Governor Drive Shaft.—Pack the drive shaft with Mobilgrease No. 2 and assemble.

Install the governor as outlined on page 525. Attach the drive shaft to the governor and drive adapter, being careful that there are no sharp bends that will cause excessive strains in the shaft when it is tightened in place.

Relay.—Check the relay points for good contact alignment. In the neutral position there is approximately ⅛-in. clearance between contacts.

Replace the relay in the box, making sure all electrical connections are tight and that there is no possibility of short circuits.

Install the relay in the airplane and connect the disconnect plugs or wire terminals to the relay.

Operation. *Starting the Engine.*—Set the safety switch to "On" position. *This switch should be "On" at all times when the airplane is being operated.*

Set the selector switch to "Automatic" (constant speed).

Start and warm up the engine.

Take-off.—Set the selector switch to "Automatic."

Place the constant-speed lever control to full forward position (take-off r.p.m.). If a crank-and-dial type of control is used, set it for take-off r.p.m.

Adjust the throttle to obtain the desired manifold pressure. The engine r.p.m. will remain constant at the speed determined by the constant-speed control setting.

Climb and Normal Flight (Constant Speed).—Move the control lever aft slowly, or adjust the dial setting, until the tachometer reads the desired r.p.m.

On multiengine planes, synchronize the engines by adjusting the constant-speed control levers.

Any combination of engine r.p.m. and manifold pressure may be obtained within the operating limitations of the engine by independent adjustment of the engine throttle and constant-speed control.

Manual Selective Control.—Set the selector switch to "Manual."

Hold the r.p.m. control switch to either "Increase RPM" or "Decrease RPM" until the tachometer reads the desired r.p.m.; then release the switch.

The propeller in manual selective control is essentially a fixed-pitch propeller, controllable, through operation of the "Increase Decrease RPM" switch, to any pitch within the flight range. (In manual selective control the constant-speed control is not used.) Propellers in manual selective control may be synchronized by the operation of the "Increase Decrease RPM" switches, or adjustment of engine throttles.

Notes: 1. This type of control for level cruising flight is very practical since the propeller will be operating as a "fixed-pitch propeller" and any loss of engine power will be readily detected by a decrease in engine r.p.m.

2. It is also desirable to use manual selective control when making fuel mixture adjustments or checking magnetos.

Landing.—Set the selector switch to "Automatic."

Adjust the constant-speed control to cruising r.p.m. As the throttles are closed, the propeller automatically returns to low pitch. A setting for cruising r.p.m. will prevent overrevving of the engine if the throttle is opened suddenly.

Feathering.—In case of engine failure in flight where it is desirable to stop rotation of the engine, the propeller should be feathered as follows:

Throw the feather switch, usually located under a red guard, to "Feather" position.

The propeller will automatically change to feather pitch and stop at that position.

To return the propeller to flight pitch, throw the "Feather" switch to "Normal" and the selective switch to "Automatic," and the propeller will automatically return to normal pitch settings.

The propeller pitch may also be returned from "Feather" to within the flight range by setting the selector switch to "Manual" and holding the manual control switch to "Increase RPM" until the flight pitch is reached.

Note: On installations not having a separate feather switch, it will be necessary to use manual control and the "Decrease RPM" switch for feathering. Feather return is accomplished by placing the selector switch back to automatic.

Caution. If it is desired to feather the propeller at any time except in an emergency, it is advisable to shut off the fuel supply and run the fuel out of the engine, then proceed with feathering. This is to prevent an accumulation of fuel in the engine and exhaust system from causing a fire hazard.

An inactive engine in flight cools rapidly. Hence, when starting the engine in flight, the throttle should be almost closed and the engine allowed to warm up thoroughly before the throttle is opened.

Reset Safety Switch.—If this switch is opened by an overload, it may be readily closed by throwing the switch to full "Off" position and then throwing it to full "On" position.

Pilot's Check List

SINGLE ENGINE

Safety Switch—To be "On" at all times when operating the airplane.
Take-off—Selector switch to "Automatic."
Governor control set for take-off r.p.m.
Cruising—Select desired r.p.m. with the governor control.
Adjust the manifold pressure with the throttle.
Manual Selective Control—Selector switch to "Manual."
Select the desired r.p.m. with the "Increase-Decrease RPM" switch.
Landing—Selector switch to "Automatic."
Governor control to cruising r.p.m.
Reset Safety Switch—When the switch opens due to overload.
Move to full "Off" then to full "On."

MULTIENGINE

Safety Switches—To be "On" at all times when operating the airplane.
Take-off—Selector switches to "Automatic."
Governor control levers full forward.
Cruising—Select the desired r.p.m. with the governor controls.
Adjust the manifold pressures with the throttles.
Manual Selective Control—Selector switch to "Manual."
Adjust the r.p.m. with the "Increase-Decrease RPM" switches.
Landing—Selector switches to "Automatic."
Governor controls to "Cruising RPM."
Feathering—Feather switch to "Feather" position.
Return to Normal—Feather switch to "Normal."
Selector switch to "Automatic."
Reset Safety Switch—When the switch opens due to overload.
Move to full "Off" then to full "On."

The Controls of the Proportional Governor

This control system employs a spring-loaded centrifugal-type governor having an oil servo-operated switch mechanism. The governor is designed to be mounted on the governor drive pad of the engine. The r.p.m. setting of the governor is varied with a cockpit control lever which is connected to the governor by means of push-pull rods or control cables. Suitable cockpit switches, a relay, wiring, and necessary conduits to the governor and propeller complete the propeller control system.

Governor (Fig. 67).—The purpose of the governor is to maintain the engine at a constant speed by changing the propeller blade angle to correct for varying conditions of operation such as engine power, airplane speed, and air density.

Basically the governor is a single-pole, double-throw switch, placed in the propeller circuit and operated automatically by the flyweight force which is affected by variations in governor speed. An oil servo mechanism is employed to provide movement of the center contact of the switch. Oil pressure from the engine oil system is used to operate the servo and is regulated by means of a valve which is linked to the flyweights. The standard governor has an integral oil pump and relief valve which accurately maintains a constant pressure regardless of any variations in engine oil pressure. A helical spring counterbalances the flyweight forces so that at governing speed the flyweight valve will supply only enough oil pressure to balance the servo piston against its spring, thereby holding the center switch contact in the "neutral" or "off" position.

With this arrangement, the flyweight forces reflect any changes in engine speed by corresponding movement of the servo piston and the center switch contact.

Should the engine speed increase, the flyweights move outward, causing the valve to increase the oil pressure to the servo, thereby moving the center switch contact in the upward direction. Should the engine speed decrease, the flyweights move toward the center, causing the valve to decrease the oil pressure to the servo and consequently moving the center switch contact downward.

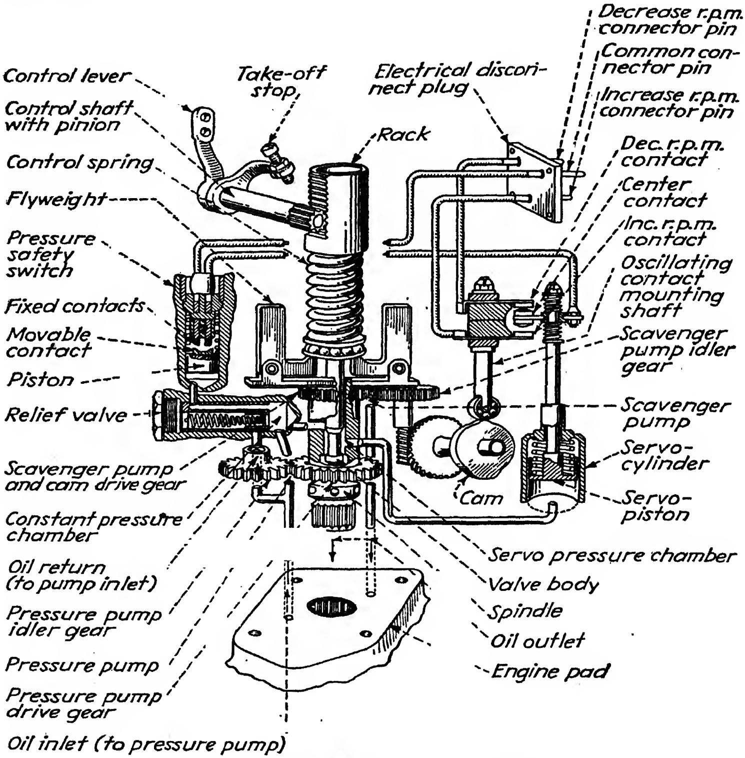


FIG. 67.—Schematic diagram of proportional governor.

Two contacts, one above and one below the center switch contact, represent opposite poles of a double-throw switch. The upper contact provides a means for closing the *decrease* r.p.m. propeller circuit; the lower contact provides a means for closing the *increase* r.p.m. propeller circuit.

To provide for proportional corrections of speed variations within fine limits and to provide electrical contact that will effectively make and break the circuit, the decrease and increase r.p.m. contacts are mounted on a shaft that allows these contacts to oscillate up and down within a given range.

This movement of the contacts is caused by having the mounting shaft ride on a cam which is geared to the governor spindle.

The "Decrease RPM" and "Increase RPM" contacts are spaced so as to permit them to oscillate by following the movements of the cam without touching the "center" contact when it is in the "neutral" position. Should the engine speed increase or decrease slightly, the "center" contact will move toward the decrease or increase r.p.m. contact, as the case may be. It will be touched by this outer contact momentarily each time the cam motion brings the outer contact toward the "center" contact. Thus, for a slight increase or decrease in speed, the amount of blade angle correction brought about by momentary contact is sufficient to supply the exact correction for the off-speed condition.

For greater off-speed conditions, the "center" contact will move farther toward either of the oscillating contacts, thereby closing the circuit for a longer period. The period when the contacts remain in touch with each other increases as the off-speed condition increases, until finally the two will be making continuous contact. Thus, when off-speed conditions exceed approximately 40 *r.p.m. above speed* or 75 *r.p.m. below speed,* continuous contact is established.

The governor consists of two major assemblies designated, respectively, as the "upper case" and the "lower case." Both are dural castings which have been anodized and painted for protection against corrosion. The upper case contains a rack, pinion, and lever which function together to control the force of the flyweight spring. The lower case contains an oil pump, a relief valve, a pressure switch, a flyweight spindle assembly, and a contact mechanism. Early type proportional governors did not include the oil pump and relief valve (see Figs. 67 and 68).

Spindle Assembly.—The spindle assembly, as mentioned, carries the flyweights and the valve. The lower end of the spindle is splined to fit the standard governor drive shaft in the engine. A small amount of oil is by-passed from the oil supply to lubricate the flyweights and the bearing on which the governor adjusting spring is seated. The flyweights are enclosed in an aluminum shell mounted on the top of the spindle. This shell prevents excessive churning of the oil by the flyweights.

The flyweight arms are connected to the balanced sliding valve inside of the hollow spindle so that movement of the weights under centrifugal force creates a corresponding movement of the valve in the spindle. Valve movements simultaneously change the inlet and the outlet orifice, thereby regulating the pressure drop through the valve chamber. This change in pressure is in turn transmitted by way of oil passages to the servo cylinder, thereby directly affecting the position of the servo piston and the center switch contact.

Pressure Pump and Relief Valve.—The pressure pump consists of a drive gear pinned to the lower end of the spindle and an adjoining idler gear. These gears are housed in the bottom of the governor case beneath a cover plate. The relief valve is located in one side of the lower housing and consists of a spring-loaded plunger mounted in a steel sleeve. The purpose of the pump and relief valve is to provide constant oil pressure to the flyweight valve regardless of variations in engine oil pressure. The relief valve is not adjustable since the spring provided will maintain a pressure of approximately 45 lb. per sq. in. The pressure pump and relief valve were not incorporated in early proportional governors which depended upon the engine for operating pressure.

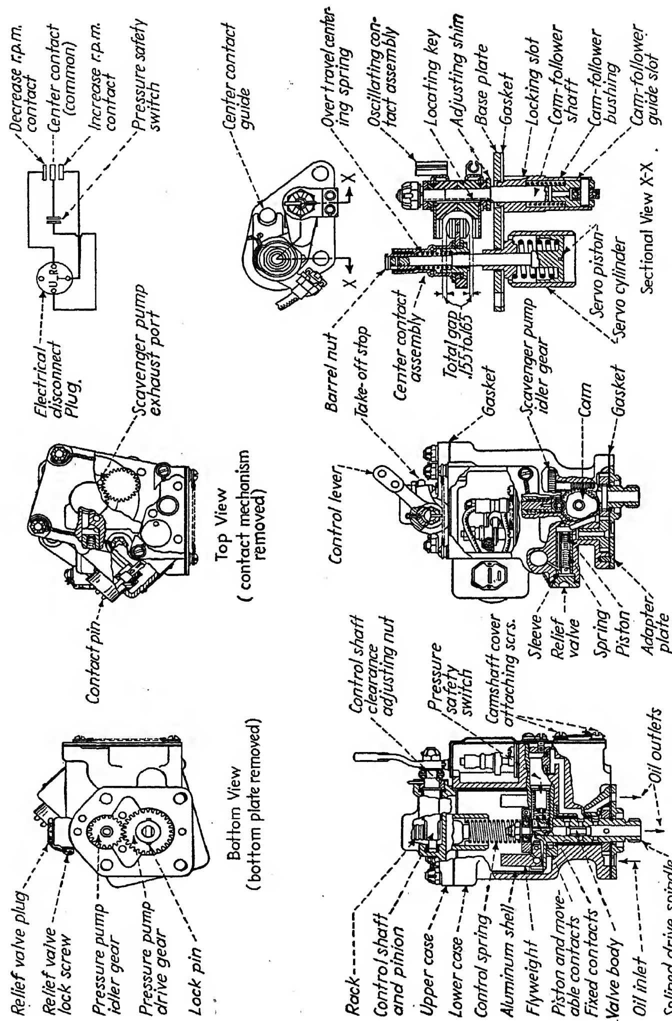


Fig. 68.—Assembly drawing of proportional governor.

Scavenger Pump.—In order to prevent the governor case from becoming excessively filled with oil, a scavenger pump is located at the lower end of the flyweight compartment. This pump consists of a small spur gear pressed on the spindle shaft and meshing with a second spur gear. Excess oil is picked up by the pump and discharged through the lower portion of the hollow spindle and thus back to the engine. This scavenging system, together with the action of the aluminum shell which encloses the flyweights, enables the governor to operate satisfactorily when mounted in either a horizontal or vertical position.

Servo Cylinder.—A small phosphor-bronze cylinder is placed in the lower portion of the lower case. In this cylinder is a steel piston backed by a coil spring which serves to counterbalance the oil pressure applied to the piston. This oil pressure is transmitted from the valve chamber as described. A shaft, which is an integral part of the piston, extends through the upper end of the servo cylinder and supports the center contact assembly of the switch.

The purpose of the servo mechanism is to move the center switch contact in response to any movement of the flyweights.

Pressure Safety Switch.—Since the servo mechanism in the governor would cease to operate if a failure should occur in the engine oil supply, an oil pressure switch is employed to disconnect the governor automatically from the propeller circuit. In effect this will cause the propeller blades to remain fixed at the angle they had when the oil loss occurred. Opening the automatic control circuit in this manner does not in any way affect the operation of the manual selective control system.

The pressure switch consists of two tungsten-tipped contacts placed at one end of a cylindrical hole in the governor case and a piston having a mating tungsten contact. The piston with its contact operates in the cylinder and is held apart from the mating contacts by a coil spring. The main oil pressure passage from the relief valve is connected to the switch chamber so that when the oil pressure overcomes the spring pressure, the contacts close the circuit. This switch is connected to the lead between the external disconnect plug and the center governor contact.

Governor Contacts.—The governor switch contact mechanism consists of three tungsten-faced contacts. As described, the double-faced center contact assembly is attached to the servo piston shaft and is held in place by a centering spring which permits the contact to slide on the piston shaft when pressure is applied against either face of the contact. This sliding action is necessary in order to follow the movements of the oscillating contacts.

The oscillating contacts are connected in the propeller circuit by flexible leads from the disconnect plug. The upper contact connects to the decrease r.p.m. circuit and the lower contact connects to the increase r.p.m. circuit.

The oscillating contacts are rigidly attached to a shaft having a roller at the lower end which rides on a cam driven from the governor spindle. A coil spring holds the cam follower against the cam so that the contacts will oscillate in response to the motion of the cam.

Electrical Disconnect Plug.—To facilitate the electrical connections between the governor and the propeller circuit, a disconnect plug is attached to the side of the lower governor case. Three wires are required to complete the internal governor circuit. One is connected through the oil pressure safety switch to the center contact, and the other two are connected directly to the decrease r.p.m. and increase r.p.m. contacts. The plug is a standard type suitable for ⅝-in. flexible shielded conduit.

Upper Case Assembly.—The upper case houses a nitrided steel rack and pinion which is used for controlling the governing r.p.m. The rack, which operates vertically in the case, bears on the upper end of the flyweight spring. The movements of the rack are controlled by a pinion shaft which extends to the outside of the case. A take-off r.p.m. limit arm having an adjustable stop screw is pinned to the outer end of the shaft. A control lever or pulley may be utilized to provide a connection, by way of push-pull rods or cables, to the cockpit control unit.

Cockpit Control Switches. *Selector Switch* (Fig. 69).—The selector switch has four positions: (1) automatic, (2) off, (3) increase r.p.m., (4) decrease r.p.m. This switch selects the type of control that is desired, and provides selective fixed-pitch control. When the selector switch is placed in "Automatic," the propeller will provide automatic constant-speed control. Placed in the "Off" position, the propeller will operate as a fixed-pitch propeller. To adjust the blade angles manually, the selector switch

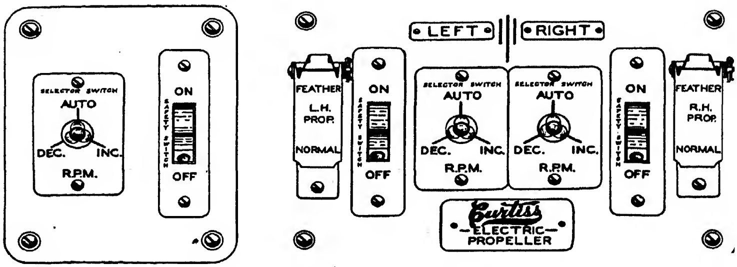


Fig. 69.—Switch panel for twin-engine cockpit.

must be held momentarily toward "Increase RPM" or "Decrease RPM" as required.

Feather Switch.—This switch is a double-pole type having two positions. It is used only in multiengined installations, to break the normal propeller circuit and complete the feather circuit. During all normal propeller operations this switch is placed in the "normal" position. A switch guard is provided to prevent accidental operation of this switch.

Thermal Overload Switch.—A thermal circuit breaker type switch is part of the propeller circuit and serves a dual purpose: it provides protection against excessive overloads and is used also as a propeller line switch. If this switch is opened by an overload on the propeller circuit, it may be closed again by placing the switch to the full "On" position.

Relay (Figs. 70 and 71).—A relay is required in the control system of each propeller. In reality, the relay is the heavy-duty switching mechanism of the propeller control circuit. Its purpose is to carry the propeller operating current to the pitch change motor during the time that the propeller is operating in *automatic* control. A low amperage current, controlled by the governor contacts, energizes the relay solenoid coils. These energized coils act upon the soft iron armature of the relay which in turn cause the heavy relay points to make or break the propeller circuit.

Fast Feathering Booster.—For rapid feathering, most installations employ *a fast feathering voltage booster* which is used only during the feather opera-

tion. This unit is included in the propeller control system for the purpose of quadrupling the normal voltage to the pitch change motor so as to increase the rate of pitch change approximately four times. The voltage booster, only one of which is required in each airplane, is a single-motor generator unit. When the feather circuit is closed, a solenoid switch, which is connected in series with the feathering circuit, automatically puts the booster in operation. Upon reaching the feather setting, the limit switch in the

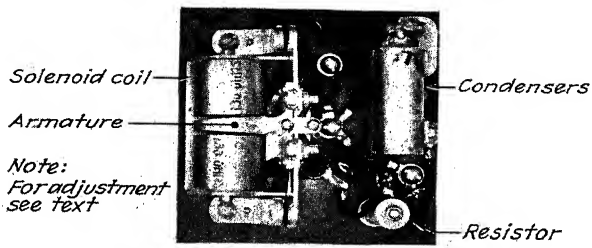


FIG. 70.—Heavy-duty relay assembly.

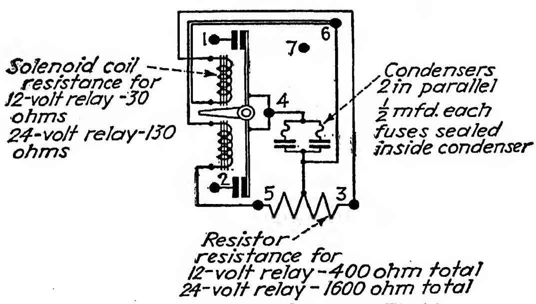


FIG. 71.—Diagram of the relay in Fig. 70.

propeller opens, the booster solenoid is then released, and all the propeller circuits are open.

Installation Requirements

General requirements for the typical installation are outlined here. The manufacturer should, however, be consulted before a new installation is attempted.

Governor Installation (Fig. 72).—The governor is usually mounted on the standard governor drive pad on the engine nose. Special adapters are available to permit installation on an accessory drive on the rear of the engine. The governor base is designed to accommodate the studs furnished with engines in accordance with S.A.E. specifications. A gasket is furnished

with the governor for installation between the governor and the engine pad, although the standard gasket furnished with the engine may be used.

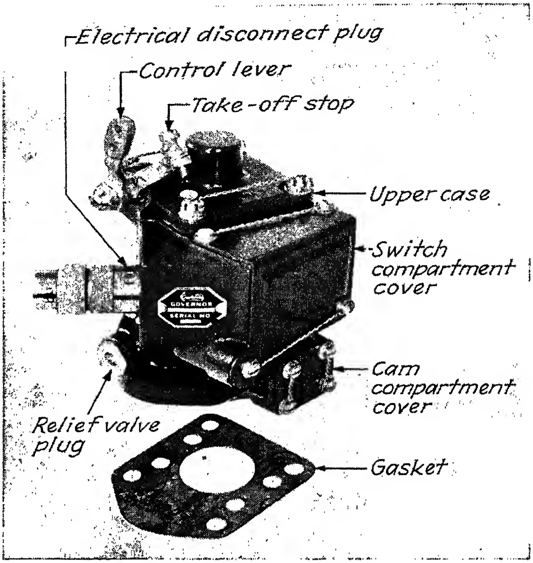


FIG. 72.—The proportional governor.

Relay (Figs. 73 and 74).—The relay should be mounted in the engine compartment in an accessible location, preferably on the fire wall.

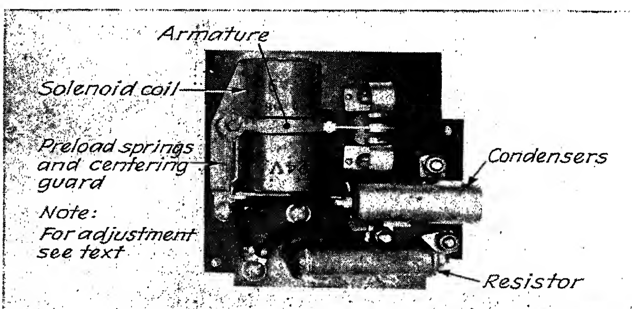


FIG. 73.—Relay for governor installation—early damped type.

If the relay is located on the engine mount, it is advisable to provide a support that will minimize vibration.

The relay is mounted in a junction box provided for the connection of all propeller wiring in the vicinity of the engine compartment. It can be supplied with or without disconnect plugs, according to the requirements of the particular installation.

Wiring and Conduits.—It is recommended that all propeller wiring be carried in conduits separate from all other airplane wiring. Solid conduits should be used wherever possible, although flexible conduit is normally used from the governor and brush assembly to the relay box in the engine compartment. Figures 75 and 76 show wiring diagrams for both single- and twin-engine planes.

All propeller wiring must be of sufficient size to limit the voltage drop in the complete circuit between the propeller and power source as follows:

For 12-volt installations the voltage drop must not exceed 1.2 volts when the circuit load is 20 amp.

For 24-volt installations the voltage drop must not exceed 1.2 volts when the circuit load is 10 amp.

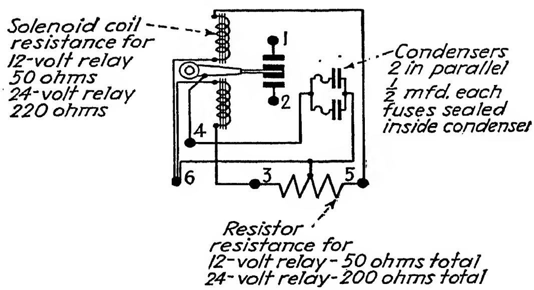


FIG. 74.—Diagram of the relay in Fig. 73.

All terminal lugs must be firmly soldered to the ends of the wires and care must be taken to prevent terminals from touching other terminals or connector housings. Wedge-on terminals, or an equivalent type of wire terminal, may be used.

Switches.—It is recommended that the switches supplied with the propeller be used.

All propeller switches are to be within easy reach of the pilot; a convenient location is slightly forward or to his left. It is desirable to group all propeller switches together and, if possible, on a small individual panel.

Controls.—A quadrant lever cockpit control unit has been found to be most practical for controlling the governor r.p.m. setting. The cockpit control may be connected to the governor by push-pull rods and bell cranks or by two-way control cables and suitable pulleys. The governor is provided with a lever that can be replaced with a pulley if cable control is used.

The upper governor case which carries the control shaft can easily be located in any one of four positions, so that it may readily be adapted to various installation requirements.

A take-off r.p.m. stop is provided as an integral part of the governor. For angular movements of the governor control against r.p.m. settings, the governor installation drawing should be consulted.

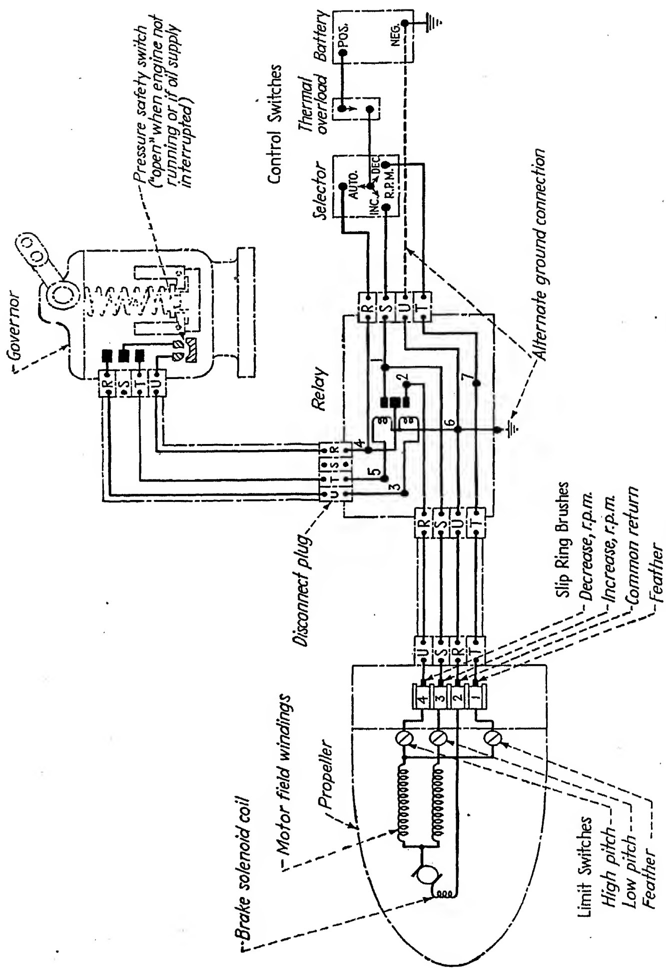


FIG. 75.—Wiring diagram for single-engine installation.

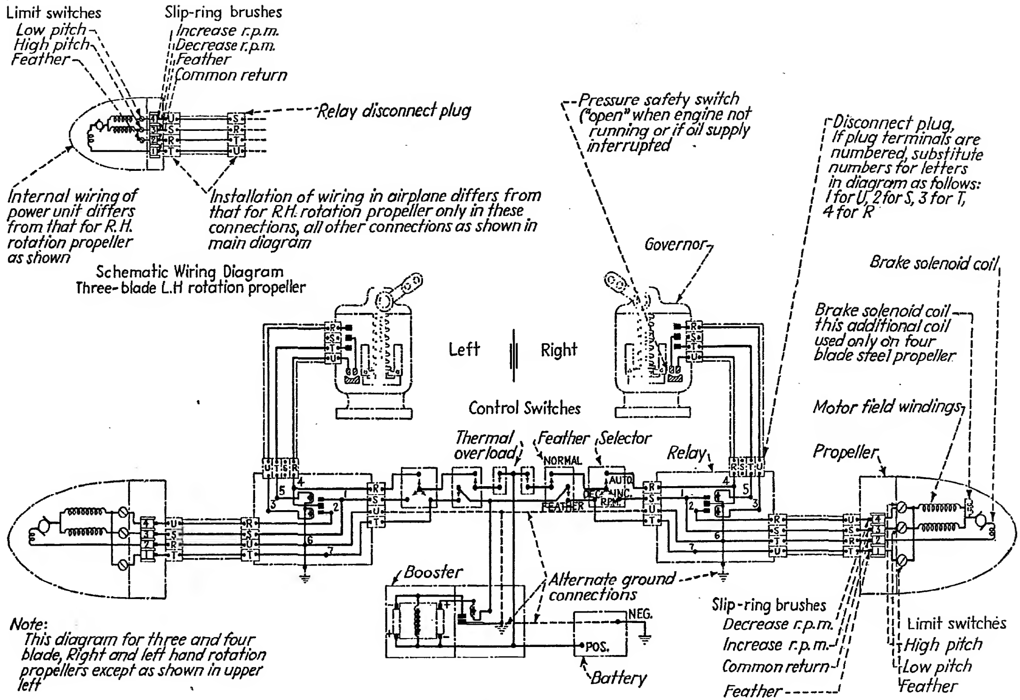


FIG. 76.—Wiring diagram for twin-engine propellers with proportional governor.

Filter.—A radio-frequency filter is placed in the relay circuit, if required, to eliminate any possibility of radio interference due to the operation of the propeller.

Removal and Disassembly of Governor

Removal of Governor from Engine.—Disconnect the control rod or cables from the governor.

Disconnect the conduit and wire connections by detaching the disconnect plug.

Remove the lock wire and nuts that attach the governor to the engine drive pad studs.

Remove the governor and gasket; cover the drive pad to prevent the entrance of dirt or other extraneous materials.

Disassembly of Governor. *Upper Case* (Fig. 68).—Remove the lock wire, washers, and four castle nuts that secure the upper case. Remove the upper case and gasket.

Remove the flyweight spring from the case.

Remove the control lever from the control shaft by removing the castle nut. Remove the take-off stop arm which is pinned to the shaft. Turning the control shaft will allow the governor spring pressure adjusting rack to be removed through the guide on the under side of the cover.

Note: As a means of reindexing the rack and gear to the same take-off setting, measure the distance from the lower end of the rack to the end of the guide while the take-off stop arm on the shaft rests securely against the stop on the cover. Upon reassembly, engage the rack with the pinion on the control shaft to obtain this same measurement.

Remove the control shaft retaining nut and withdraw the shaft.

Oil Pressure Pump.—Remove two countersunk screws on the bottom of the adapter plate; then remove the base plate and gasket.

Remove the idler gear.

Remove the snap ring from its position on the spindle below the drive gear.

Slide the drive gear off the spindle.

Rotate the spindle until the drive gear pin is pointing toward the idler gear well, and remove the pin.

Flyweight Spindle.—Remove the spindle from the case. On earlier types not employing the oil pressure pump, remove the snap ring from the drive end of the spindle and withdraw the spindle from the case.

To remove the scavenger pump idler gear from the flyweight chamber, rotate by hand in the direction of the governor rotation indicated on the plate attached to the case. This is necessary because a worm is cut on the end of this gear shaft. Prying with tools may damage this worm or its mating teeth on the cam gear.

Insert a soft metal or wooden rod into the lower end of the hollow spindle and push out the valve body. Remove the retaining nut and bearing from the valve body.

Remove lock wire, four screws, and washers that secure the aluminum shell to the top of the spindle. Remove the shell.

Remove the four small pins from the shell seating surface on top of the spindle by inserting a piece of fine wire in the holes in the pins.

Push out two flyweight pivot pins and remove the flyweight assembly from the spindle.

Disassemble the flyweights and valve bearing seat from the linkage by removing the pivot pin and wire locks.

Contact Mechanism.—Remove the lock wire, washers, and screws that attach the cover to the switch compartment. Remove the cover and gasket.

Cut the lock wire and remove the center contact guide stud.

Remove the cotter pin and nut that secure the oscillating contact assembly together. Remove the washers, insulating washers, insulating spacers, wire terminals, contacts, and laminated shim from the cam follower shaft. Remove the key that locates the insulating spacers on the shaft.

Remove the nut and tab washer from the wire terminal on the center contact assembly.

Remove the lock wire and two screws that hold the base plate in the switch compartment. The center contact assembly, base plate, and piston may now be removed from the governor for further disassembly.

Remove the lock pin and barrel nut from the upper end of the center contact assembly. This may readily be accomplished by pushing the piston into its cylinder and pressing the center contact toward the piston at the same time.

Remove the center contact assembly, base plate, gasket, cylinder, and spring from the piston shaft.

Cut the lock wire from the center contact assembly bell-shaped nut and unscrew it. Remove the spring and two washers from the bore of the assembly. Remove the insulating washers, wire terminal connection plate, contact plate, and fiber shear pin.

Cam Follower and Cam.—Remove the lock pin that secures the cam follower bushing in the case by using a No. 4-40 machine screw as a puller.

Remove the cam follower assembly from the case and disassemble the same.

Remove the lock wire, four screws, and washers that secure the camshaft bearing plate to the front side of the case. Remove the plate and gasket and withdraw the camshaft. The cam is pinned to the shaft and need not be removed.

Pressure Safety Switch.—Remove the large plug with a screw-driver slot from the front side of the case. The early type governors have this plug at the lower end of case. After this plug has been removed, the contact piston and spring may be removed.

Remove the safety switch contact assembly by sliding the connecting wires through the slot provided in the case.

Remove the spring and contact piston. Before removing the contact assembly, it will be necessary to disconnect the electrical lead from the disconnect plug.

The safety switch contact assembly in the early proportional governor is pressed into the lower end of the case and may be removed by preheating the case in the vicinity of the switch with live steam or a hot-air blower.

Electrical Disconnect Plug.—Remove the four screws that secure the disconnect plug socket to the governor case. The socket may then be disassembled into its component parts.

Relief Valve.—Remove the safety wire.

Remove the hexagonal plug and gasket from the side of the case.

Remove the locking screw and gasket from the side of the case.

Remove the relief valve spring and the steel sleeve.

Remove the piston from the steel sleeve.

Inspection of Governor Parts

Upper Case.—Examine the teeth on the control shaft and on the rack for excessive wear or damage.

Examine the parts for excessive looseness of the control shaft in the bushings and for excessive end play in conjunction with the retaining nut.

Examine the rack and housing for excessive looseness.

Inspect the rack and pinion for excessive wear or damage and for smooth, free operation when assembled.

Flyweight Spindle and Component Parts.—The spindle should turn freely in the bushing and must not have an excessive amount of side clearance.

Inspect the scavenger pump gears for excessive wear or damage.

Inspect the valve bore in the spindle and surfaces of the valve body for a smooth, polished finish. Both surfaces must be absolutely free from burrs, rough edges, or scratches.

Examine the valve body bearing for roughness or excessive wear. Valve orifice edges should be sharp and free from nicks.

Examine the flyweight assembly and valve body for free operation. The flyweights must move through their entire range without any tendency to bind. Flyweight pins and link pins that show signs of excessive wear should be replaced.

Inspect the condition of the flyweight spring, noting that the spring is straight and the ends square.

Examine the passages in the spindle and valve body for possible restrictions.

In the early type governor not employing an oil pressure pump, the snap ring on the lower end of the spindle should not show signs of wearing into the shoulder of the bushing.

Contact Mechanism.—Examine the center contact assembly for full, unrestricted travel and smooth operation on the piston shaft.

Inspect the top locking nut for smoothness and freedom from burrs and rough edges.

Examine the cam follower shaft in its bushing for free operation and possible wear. Check the ball bearing cam follower for roughness and wear. Inspect the servo piston and cylinder for excessive wear between the two parts and for smooth, free operation.

Inspect the cam and cam gear teeth for wear or damage.

Inspect the bronze camshaft bushings located in the case and cover for excessive wear.

Inspect the fiber shear pin, insulating washers, and blocks for any signs of cracks or deterioration from oil and heat.

Inspect the wire insulation and connections at the contacts and at the disconnect plug.

Contact points are to be smooth and free from surface pits; if they are pitted, they should be stoned smooth or replaced.

Pressure Safety Switch.—Inspect the contacting surfaces of the pressure safety switch contacts for smoothness. These may be polished smooth but should be replaced if excessively pitted.

Inspect the pressure switch piston for a free sliding fit in the governor case. Inspect the outer surface of the piston for possible roughness or galling.

Examine the contact point in the piston for free swivel action, making sure that the contact extends 0.010 in. above the fiber collar.

Inspect the condition of the switch wiring.

Pressure Pump and Relief Valve.—Examine the gear teeth for wear or damage.

Inspect the idler gear for free rotation in its well.

Examine the driver gear pin for any signs of damage or wear.

Inspect all oil passages to and from the pump for possible restrictions.

Examine the plunger and spring for possible wear.

General.—Blow through all the oil passages in the lower case, spindle, and valve body; check for possible restrictions and deposits of extraneous matter.

Inspect the screws that hold the spindle thrust washer in the lower case for tightness; make sure that these screws are securely staked.

Assembly of Governor

Pressure Safety Switch (Fig. 67).—Standard-type proportional governor:

Insert the pressure switch piston with the contact facing outward.

Place the pressure spring and gasket over the switch assembly and insert it in the chamber. Care should be taken that the wires go through the slot provided and that the spring is resting on the shoulder of the piston.

Connect the wires from the pressure switch to the electrical disconnect plug and to the center contact assembly.

Install the retaining screw and tighten it in the case.

Early-type proportional governor did not have a pressure pump.

Insert the pressure safety switch assembly in the lower governor case. Using a driving tube slightly under ½ in. O.D., tap the switch assembly securely into place in the case. Connect the wire leads from the pressure safety switch to the electrical disconnect plug and the center contact assembly.

Install the piston spring with a washer at each end; locate the piston itself in the lower case and place the contact end of the piston so that it faces toward the switch contacts. Install and tighten the retaining screw in the case.

Electrical Disconnect Plug.—Assemble the three contact pins in the disconnect plug assembly with connections as shown on the assembly drawing. Attach the disconnect plug assembly to the case with screws and lock washers.

Camshaft Installation.—The cam is pinned to the shaft at the factory and normally is not removed during overhaul. Insert the cam and shaft assembly into the governor housing; fasten the front bearing plate and gasket to the case with four screws and plain washers. Secure the screws with safety wire. The shaft must rotate freely after installation is completed.

Cam Follower Assembly Installation.—Assemble the bushing, spring, and bearing on the cam follower shaft. The bearing pin serves as a guide to prevent rotation of the cam follower shaft.

Insert the cam follower assembly into the lower case, making sure that the keyway in the shaft faces the center contact assembly. Press the bushing down against the spring while installing the locking pin through the front case. The locking pin must enter the slot provided for it in the bushing.

Center Contact Assembly and Servo-cylinder Installation.—Assemble the center contact assembly as shown in Fig. 68, making sure that the bell-shaped nut is securely tightened and safety wired.

Insert the piston and spring into the servo cylinder. Place a steel base plate and gasket over the piston shaft and then install the center contact assembly on the shaft and secure it with the barrel nut. The barrel nut is

locked in position by a small locking pin which is placed in a slot in the piston shaft before installing the barrel nut. The barrel nut is locked by bending the locking pin to fit a slot in the nut. Proper adjustment is obtained by gradually tightening the barrel nut until the assembly has 0.002-in. max. end play between the sleeve and the washer when the shaft shoulder is against the lower washer.

Note: Excessive end play will result from having the barrel nut either too loose or too tight. Install the center contact and the servo-cylinder assembly into the governor case and fasten them into place with two screws and safety wire.

Decrease and Increase R.P.M. Contact Installation.—Install washers, laminated shim, spacer blocks, contact plates, and wire terminals on the cam follower shaft; then install the retaining nut. The parts are held in their proper places by a key in the shaft and in the micarta blocks. For proper sequence details refer to Fig. 68.

The total gap between the faces of the two oscillating contacts is adjusted by filing or by placing a shim between the mating surfaces of the spacer blocks.

Install the center contact guiding stud and secure it with safety wire. **Caution.** Inspect the stud for straightness before replacing it. Do not bend it while safety-wiring. A bent stud will cause binding of the center contact assembly.

Attach the wire from the pressure safety switch to the center contact wire terminal and secure the nut by bending the tabs of the locking washer.

Flyweight Spindle Assembly and Installation.—Assemble the bearing and bearing cup to the valve body and secure with a nut and cotter pin.

Assemble the flyweights and linkage to the spindle. Secure the pivot pins in place with steel locking wire provided for that purpose.

Attach the aluminum shell to the spindle with four screws and washers. Safety-wire the screws to the holes in the shell. Install the valve body in the spindle.

Install the scavenger idler gear in the case. This gear should be rotated in the opposite direction of that indicated on the plate attached to the case and eased rather than forced into place, since the worm gear engages with the camshaft gear.

Place the spindle assembly in the governor case. In early type governors, install the ring on the drive end of the spindle shaft.

Pressure Pump.—Rotate the spindle so the locking pin hole is pointing toward the idler gear well.

Insert the locking pin. Care should be taken that the pin is centered and that the flat ends are parallel with the spindle shaft.

Place the drive gear over the spindle shaft, index with a pin, and slide into place.

Place the idler gear in the well and index with the drive gear teeth.

Set the lower cover plate and paper gasket in place; insert screws and tighten.

Upper Case Assembly and Installation.—Place the rack in the upper case and install the control shaft, meshing the teeth so as to align the index marks which will be readily found.

Install the shaft retaining nut in the case and secure with a cotter pin. If necessary, the face of the retaining nut should be filed so as to provide a small amount of end play when the nut is tight. The shaft must operate freely and smoothly when assembled.

Install the take-off r.p.m. stop arm and secure with a $\frac{3}{32}$-in. steel rivet.

Install the control arm at the proper angle on the shaft and secure with nut and cotter pin.

Place a gasket on the top face of the lower governor case; install the fly-weight spring and attach the upper case assembly; secure the upper case with four nuts, washers, and safety wire. Be sure that the control arm is located on the correct side of the governor to meet the installation requirements.

Relief Valve.—Insert the bronze plunger in the steel sleeve.

Place the relief spring with taper end first in the plunger.

Insert the complete valve assembly in the governor case.

Place a locating screw with gasket through the hole provided in the housing and at the same time through the hole in the steel sleeve. Depress the spring so the locating screw will move to the opposite hole on the other side of steel sleeve. Tighten the locating screw.

Install a hexagon plug with gasket; tighten and safety-wire.

Governor Test

The functioning of the governor should be examined with a suitable testing device upon reassembly of the governor contact mechanism or after any changes in adjustment thereof.

General Requirements of Testing Device.—The equipment required to test the operation of a proportional governor consists of a variable speed driving unit, a tachometer, a suitable mounting pad, and an oil supply system with, perhaps, an oil pump and an electrical indicating system.

The variable speed driving unit must be capable of maintaining a selected constant speed within ± 2 r.p.m. An accurate tachometer is necessary to indicate the operating speeds. The governor is connected to the driving unit by a mounting pad essentially similar to that of the engine. A reservoir capable of holding approximately 1 gal. of oil and located not more than 12 in. below the governor may be used in conjunction with oil lines to supply oil to the mounting pad.

The standard proportional governor having the integral oil pump and relief valve is capable of supplying the oil pressure necessary for the proper operation of the governor. The early-type proportional governor which does not contain an oil pump will require an auxiliary pump in conjunction with the testing device. For this purpose it is sometimes convenient to use a small unit called a "sandwich" pump between the governor and the mounting pad. This unit is a gear pump arranged to transmit the driving force from the engine to the governor at a pressure controlled by an integral relief valve. If a sandwich pump is not available for testing the early type proportional governor, it will be necessary to make use of some other type of separately driven oil pump together with a relief valve to control the pressure. The pump used for this purpose should be able to maintain an oil flow of approximately 3 pt. per min. at a pressure of 38 lb. per sq. in. at the governor mounting pad.

The electrical indicating system is for the purpose of registering the closing of the *increase* or *decrease* r.p.m. circuits. A light connected to the *increase* and one to the *decrease* circuits through the disconnect plug will provide a simple method of designating the closing of each circuit. A light will be *on* when either the *increase* or *decrease* circuit is closed, but the *on-speed* condition is registered when both lights are *off*.

Governor Operating Test.—Place the governor on the mounting pad, connect the indicating lights, and supply oil or oil pressure as already indi-

cated. Run the governor at a speed that approximately equals that of the governor drive at the cruising speed of the engine on which the governor will be used. Secure the control lever in a position that will provide an *on-speed* setting and note the tachometer reading.

Gradually increase the speed of the governor to a point where the *decrease r.p.m.* light changes from intermittent to continuous and note the tachometer reading. Then gradually decrease the speed to a point where the *increase r.p.m.* light changes from intermittent to continuous and note this reading. The proportional range of the governor is defined as the difference between these latter readings. For the standard unit the range should not exceed 140 r.p.m. This range should be divided as follows: 35 to 50 r.p.m. above *on-speed* before a solid *decrease r.p.m.* correction occurs, and 60 to 90 r.p.m. below *on-speed* before a solid *increase r.p.m.* correction occurs.

The early-type proportional governor (without integral pressure pump) has a proportional range of 65 to 95 r.p.m. divided as follows: 25 to 35 r.p.m. above *on-speed* and 40 to 60 r.p.m. below *on-speed.*

If the foregoing trials do not fulfill the requirements outlined, it may be necessary to make adjustment as follows:

1. Raise or lower the *increase-decrease r.p.m.* contact assembly by adding or removing shim laminations on the cam follower shaft.

2. Inspect for binding or an undue amount of friction in the flyweight valve mechanism, in the servo piston and cylinder, or in the center contact mechanism. To correct such conditions, disassemble the affected parts and polish the mating surfaces with crocus cloth.

A final test of the functioning should be made throughout the control range of the governor at intervals of approximately 300 r.p.m. Readings should be taken on both the *increase* and *decrease* r.p.m. section of the proportional range. These readings should be obtained while increasing as well as decreasing r.p.m. throughout the control range of the governor. The neutral zone or *on-speed* represents the sensitivity of the governor and usually approximates 4 or 5 r.p.m., but must not exceed 7 r.p.m.

It will be noted during tests that the tachometer reading of any fixed point, for example that at which one of the lights begins to show contact, will vary depending upon whether the point is reached while increasing or while decreasing the speed of the governor. The variation in r.p.m. shown by the difference of the two readings is called the overlap and must not exceed 5 r.p.m. Excessive overlap or poor sensitivity indicates the presence of binding or an undue amount of friction.

Take-off Stop Setting.—Determine the governor spindle speed for engine *take-off* r.p.m. *Note:* The ratio of the governor drive speed to engine speed differs for various engine models. An engine may have a governor drive ratio of 1.106 to 1. *This ratio means that at* 2,350 *engine r.p.m. the governor shaft actually turns* 2,600 *r.p.m.*

Adjust the *take-off* r.p.m. stop screw so that the governor is *on-speed* at take-off governor r.p.m.

Pressure Safety Switch.—The operation of the pressure safety switch is as follows:

Standard proportional governor (with pressure pump):

1. Operate the governor at approximately 100 r.p.m. below *on-speed* so as to obtain a continuous light.

2. Upon shutting off the flow of oil to the governor, the light should go off. This result indicates that the pressure switch has properly opened the governor circuit.

3. Upon reestablishing the oil flow to the governor, the light should again light, indicating that the switch has closed.

Early-type proportional governor (without pressure pump):

1. Run the governor 100 r.p.m. or more below the *on-speed* setting so as to obtain a continuous light.
2. Gradually reduce the oil pressure and note the point at which the light goes out, indicating that the switch has opened the governor circuit.
3. Gradually increase the pressure and note the point at which the light comes on, indicating that the switch has again closed the governor circuit.
4. The minimum oil pressure at which the switch should open is approximately 15 lb. per sq. in. The maximum oil pressure at which the switch should close is 18 lb. per sq. in. Adjustment of the switch operation between these limits may be accomplished by elongating the pressure switch spring to increase the required pressure or by removing one of the washers located at either end of the spring to decrease the pressure.

General.—A thorough inspection of the governor should be made to make sure that all screws, pins, and attaching parts have been properly secured with cotter pins or safety wire. See that the barrel nut on the upper end of the servo-piston shaft is properly secured. Be sure that the snap ring at the lower end of the splined drive spindle is in place. Replace the switch compartment cover and secure with screws and safety wire.

Operation of Relay

The relay (Figs. 70 and 71) is the heavy-duty switch mechanism of the propeller control circuit. Its purpose is to carry the propeller operating current to the pitch change motor during the time that the propeller is operating in *automatic* control. A low amperage current, controlled by the governor contacts, energizes the relay solenoid coils. These energized coils act upon the soft iron armature of the relay which in turn causes the heavy duty relay points to close the propeller circuit.

The principal component parts of a relay are as follows, together with a brief indication of the function of each.

A soft iron armature carries the movable contact points while the stationary contacts are mounted on fixed brackets.

A pair of solenoid coils are situated so that one is on each side of the movable soft iron armature body.

A resistor is connected across the coil of the relay to dampen out small fluctuating currents. This dampening action increases the life of the points by preventing chattering and causes the points to make contact solidly and break cleanly.

A condenser assembly consisting of two 0.5-microfarad condensers connected in parallel is connected between the movable contacts and the return ground for the purpose of smoothing out electrical pulsations which in some cases produce radio interference. These pulsations are voltage surges which arise when the contact points break the propeller circuit.

Each condenser is equipped with an integral fuse for circuit protection in case one of the condensers should develop a short.

The remainder of the relay parts are the necessary wires, connectors, links, pins, springs, and mounting base.

The two types of relays now in service differ from each other only in the manner in which the movable armature assemblies are arranged. The points, resistor, condensers, and coils are similar. An explanation of the major differences between armature assemblies follows:

Heavy-duty Type Relay (Fig. 71).—The armature assembly is composed of a soft iron T-shaped part with the stem located between the solenoid coils. Two transverse cross arms, located on small pins which protrude from the soft iron head, are held against the head of the T by individual preloading springs. The ends of the upper cross arm carry Elkonite contacts and extend beyond the solenoid coils. The fixed contacts are mounted on bronze brackets at opposite ends of the solenoid coils and in line with the movable contacts.

The switch cross arm bar and the centering bar are held firmly in place against the head of the armature T by a pair of semieliptical preloading springs. This assembly is arranged on a floating pin which is linked at the top and bottom of the armature to a pin fixed to the assembly support. The ruggedly constructed floating assembly with its links, cross arms, springs, washers, and large Elkonite contacts, affords a flexible motion which ensures proper alignment of the mating contacts.

Inspection and Adjustments.—1. When in neutral position, the armature should be aligned so that there will be 0.050 in. ± 0.010 in. between the fixed and the movable contacts. This adjustment may be made by bending the lower cross arm adjusting bar and/or by realigning the fixed contacts to compensate for contact wear.

2. The movable contacts should touch either fixed contact before the soft iron armature strikes the coil housing. When either mating pair of contacts are lightly touching each other, there should be 0.020 to 0.025 in. clearance between the outside edge of the movable armature body and the coil housing. This adjustment, which is necessary to ensure sufficient contact pressure between the points, may be made by proceeding according to the directions in the preceding paragraph and by realigning the coils.

3. Satisfactory closing of the contacts should be made within the following voltage:

Relay	Volts
12 volt (30 ohm)	5– 8½
24 volt (130 ohm)	10–17

4. The Elkonite points are very hard and become discolored after continued service. The contact surfaces take on a charred appearance and develope very fine pit marks. These indications are normal characteristics of this material and do not affect in any way the operation of the relay so long as satisfactory contact pressure is maintained. The Elkonite points should not be dressed or polished as this only decreases the life of the contact and does not improve the operation. The contact point material as attached to the contact arms is approximately ⅛ in. thick. If this material becomes less than $\frac{3}{32}$ in. in thickness at any point due to wear or burning, the contact should be replaced.

Inspection of Condensers and Resistor.—1. At overhaul or in the event that radio interference caused by the propellers is experienced, it will be desirable to test the condensers. To accomplish, proceed as follows:

(*a*) Remove the relay from the airplane.

(*b*) Disconnect the lead from the upper condenser by unsoldering the wire connection. Test the condensers individually. Place one lead from an ohmmeter to the condenser case; the other lead to the center post. (A violent swing of the ohmmeter at this point indicates that the condenser is shorted and should therefore be replaced.) This action will give the condenser a slight charge. Then immediately reverse the leads. A short quick response from the ohmmeter needle indicates a good condenser. No

motion of the needle indicates that the condenser fuse is burned; in this case the assembly should be replaced.

2. Examine the resistor for cracks in the porcelain casing. If the porcelain is badly cracked, replace the unit. Relays of this type have resistors rated as follows:

12-volt relay......................	200 ohms each side of center connection
24-volt relay......................	800 ohms each side of center connection

Early Damped Type Relay (Fig. 73).—In the early damped type relay, the switch arm is composed of a flexible metal reed attached to the front of the soft iron armature. Elkonite contacts are located on both sides of the front end of the reed and move between two fixed contacts. The whole switch arm is pivoted at the rear of the soft iron armature. At this pivot point a double preloading centering spring is fastened at right angles to the length of the switch arm.

Inspection and Adjustments.—1. Examine the armature for interference with the coil housing at the pivot end and realign the coils if necessary.

2. Inspect the armature for being centered and square with respect to the coil housing. Correct alignment may be secured by bending the guard for the return springs.

3. Test the armature preload by moving the center contact arm in both directions. Note that the return springs should give approximately equal loading in either direction. If necessary to adjust the preload, remove the armature and bend the return springs so that 10- to 12-oz. force applied to the end of the spring just pulls the spring away from its seat on the spring guard. A minimum of play should exist between the return springs and the armature centering bracket when the armature is reinstalled.

4. Test the relay for sufficient control pressure by lightly pressing the armature toward the coil until the movable contact just touches the fixed contact. The clearance between the armature and the coil housing should then be at least 0.015 and 0.020 in. If necessary, adjustment may be made by bending the fixed contact arms, taking care to maintain contact point alignment.

5. The armature should operate freely on its pivot pin.

6. The Elkonite points are very hard and become discolored after continued service. The contact surfaces take on a charred appearance and develop very fine pit marks. These indications are normal characteristics of this material and do not affect in any way the operation of the relay so long as satisfactory contact pressure is maintained. The Elkonite points should not be dressed or polished as this only decreases the life of the contact and does not improve the operation. The contact point material as attached to the contact arm is approximately $\frac{3}{32}$ in. thick. If this material becomes less than $\frac{1}{16}$ in. in thickness at any point due to wear or burning, the contact assembly should be replaced.

Inspection of Condensers and Resistor: 1. See Inspection of Condensers and Resistors under Heavy Duty Type Relay.

2. Examine the resistor for cracks in the porcelain casing. If the porcelain is badly cracked, replace the unit. Relays of this type have resistors rated as follows:

12-volt relay......................	25 ohms each side of center connection
24-volt relay......................	100 ohms each side of center connection

Inspection and Maintenance of Proportional Governor System

Servicing at 25 Hr.—Visually inspect the condition of all flexible propeller conduits where possible damage may occur.

Visually inspect the condition of the control rods or cables in the engine nacelle.

Servicing at 100 Hr.—To include the operations outlined in servicing at 25 hr.

Remove the contact switch cover from the governor. Inspect condition of the contacts. See that the wire leads are securely attached. Thoroughly clean the contact assemblies with cleaning solvent or gasoline, and remove any accumulated oil in the switch compartment. The contact points will not require dressing although their contacting surfaces should be cleaned with crocus cloth or fine sand paper. Place *not more than one drop* of light lubricating oil on the upper end of the shaft which supports the center contact assembly. Replace the cover.

Partially remove the relay from its box for inspection.

1. Inspect for proper mating of contact points and sufficient contact point pressure. For adjustment details, refer to Operation of Relay, page 537.

Note: The contact point material is Elkonite which is rather hard and does not require dressing or polishing.

2. Make sure the armature floats freely on its pivot pin. Lubricate if necessary with a small quantity of oil or semifluid lubricant.

3. Examine all terminals and wire connections, making sure that none are loose and that there is no possibility of the terminals touching each other. Replace the relay in the box.

Examine the flexible conduit disconnect plugs, noting the condition of the wire connections.

Inspect the cockpit control lever (or levers) to determine that it has at least ⅛-in. spring back from the full forward position as an assurance that the governor control is fully against the stop which is set for take-off r.p.m. Adjust the control cables or rods if necessary but *do not adjust the stop screw on the governor* as it is already set to provide take-off r.p.m.

On feathering installations, place the *feather switch* to *feather* position and note that the propeller blades assume the feather setting. This trial can be made without running the engine. Return the blades to normal by placing the feather switch back to *normal* and holding the selector switch to the *increase r.p.m.* position until the blades return to the low blade angle setting.

Servicing and Inspection at Overhaul.—It is recommended that the propeller control system be inspected and overhauled at the same time the propeller is completely overhauled.

Remove the governor and disassemble, inspect, reassemble, and test as already outlined.

Remove the relay and inspect as mentioned.

Since the feather booster is infrequently operated, a visual inspection will suffice at overhaul periods.

1. Remove the cover from the solenoid end of the booster and inspect the condition of the solenoid switch. Examine the wire connections and make sure that all binding posts and wire terminals are secure.

2. Remove the inspection bands and examine the armature commutators. If excessively burned, they may be polished with sandpaper; in an extreme case, the armature should be removed and the commutators turned smooth in a lathe.

3. Commutator brushes are to be approximately flush or extending beyond the outer end of the holder when riding on the commutator.

4. Examine the wire connections and leads at the brush holders noting that they are in serviceable condition.

Replace the covers.

The radio interference eliminating filter requires very little attention, although it is desirable to inspect the filter visually for possible loose wire connections. In the event that radio interference is experienced, the condensers in the filter assembly should be tested. Disconnect the single condenser lead from the terminal post on the filter coil and proceed as has been outlined.

LUBRICATION

At assembly and overhaul:

1. The spindle bearings, MRC 200-SF, should be lubricated through the plug provided with not more than 0.15 oz. (½ cu. in.) of Mobilgrease No. 2.
2. The flyweight bearing, MRC 38FF, is a double-shielded bearing and is lubricated for the life of the bearing with Texaco Starfak No. 2 and requires no lubrication at either assembly or overhaul.
3. The flyweights and plunger rod should be lubricated with a small quantity of instrument oil.
4. The sprocket or lever gears and screw bearing, Fafnir S3H, on all types should be greased at assembly and overhaul with a small quantity of Mobilgrease No. 2. Do not use more than will stick to the bearings and gears.
5. The sprocket or lever bushings should be lubricated at assembly and overhaul with a small amount of instrument oil or light engine oil.
6. Pack the flexible drive shaft with Mobilgrease No. 2 on assembly.
7. Pack the governor drive adapter with Mobilgrease No. 2.

Note: The lubricating operations necessary while the propeller is being serviced are included in Maintenance and Lubrication Instructions, page 492.

Balancing Propellers

The Curtiss Propeller Division of the Curtiss-Wright Corp. gives the following suggestions on balancing their propellers:

Mount the propeller on the balancing mandrel. The power gear assembly is to be in place during this process to hold all three blades at the same angle, approximately halfway between low and high pitch.

Mount the propeller on an accurate knife-edge balance fixture and test the balance with each blade in the horizontal position. When the propeller is correctly balanced, it will have no inclination to rotate when placed in the above position.

If one blade is heavier than the other two, add pieces of putty or modeling clay to the hub barrels of the "light" blades in approximately the same line with the balancing material in the blade shank until the propeller balances correctly. Mark the "light" blades and weigh the putty, noting the exact weights.

Place the propeller on the spindle of a checking table and remove the "light" blades. Remove the plug from the end of the balancing hole of these blades.

Hollow Steel Blade Assemblies.—Remove the nut and lock washer from the inside of the blade shank with a socket wrench. Place a steel washer of exactly the same weight as the putty on the stud and replace the nut and lock washer. Replace the plug in the blade gear.

Note: Under no circumstances are the weights that are placed around the inner wall of the blade shank to be tampered with. These weights are placed there by the manufacturer in balancing against a master blade.

Aluminum Alloy Blade Assemblies.—Add exactly the same weight of lead wool as the putty, in the hole in the end of the light blades. Drive it in tight with a brass drift, and replace the corks.

Reassemble the propeller and check it for balance.

If only slightly out of balance, one or more small balancing weights may be added to the blade nut locking slots. These weights should be located in the proper slots to maintain vertical balance. If the propeller is out of balance more than can be corrected by the external weights, it will be necessary to repeat the procedure of balancing with putty and loading the blade as already outlined.

SECTION XV

INSTRUMENTS

There are two types of aircraft instruments, (1) those that pertain to the mechanism of the plane and (2) those that help the pilot get to his destination. In the second group are the altimeter, which shows when the plane is at a safe distance above the earth, the compass, direction finder, and instruments of that sort.

Altimeters are made with varying degrees of sensitivity, as in the Kollsman, which will be shown in detail. Unfortunately their indication depends upon barometric conditions and their reading must be corrected accordingly. The following details of altimeter construction and care are due to the courtesy of the Kollsman Instrument Co., Elmhurst, Long Island. Their tachometers are also shown.

Other instruments are shown from the Pioneer Instrument Co. and the Sperry Gyroscope Co.

General suggestions for repairing airplane instruments are given on page 554. They include the kind of workbench best suited to this work and some of the tools likely to be needed. These are practically the same as those used by the watchmaker. In all this work, skill and reliability are the two main requirements for, as with the planes themselves, lives and property depend on them for safe operation.

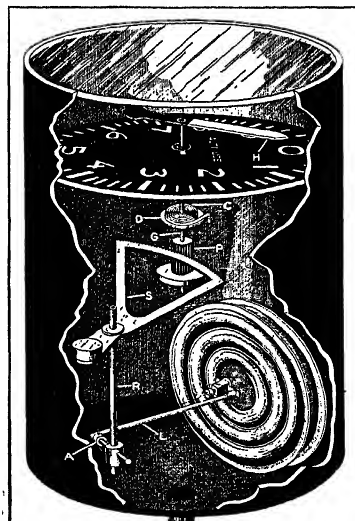


FIG. 1.—Kollsman simple altimeter.

ALTIMETER

The altimeter is a pressure gage with the dial marked in units of altitude. It gives the altitude of the plane in relation to the earth or to sea level. It works by differing pressures inside and outside an airtight diaphragm. When the pressure in the case outside the diaphragm decreases, as the plane climbs, the diaphragm expands. The expansion movement acts on a lever and, through multiplying mechanisms, indicates the change in altitude on a graduated dial. The mechanism of a Kollsman simple altimeter is shown in Fig. 1.

Expansion of the diaphragm when the air pressure in the case is lowered pushes the link *L* against the adjustment arm *A* and turns the rocking

shaft R. Fastened to shaft R is the sector S; as the shaft turns, it moves the pinion P, which is part of staff G. On the staff G is the disk D and the hairspring C, which keeps all parts tight against one another. The hand H is at the upper end of staff G and moves over the dial.

Sensitive Altimeter.—To secure a more sensitive instrument, the simple mechanism of Fig. 1 is replaced by more gearing which gives greatly increased movement to the hand for the same expansion of the diaphragm D (Fig. 2).

When the pressure in the case is lowered, it pushes link L_1 against arm A_1 and turns rocking shaft R. The sector S is a part of the rocking-shaft unit and is turned with it, turning pinion P_1 which is a part of shaft K_1. The force of the spring C, which is fixed on shaft K_1, keeps all parts tight

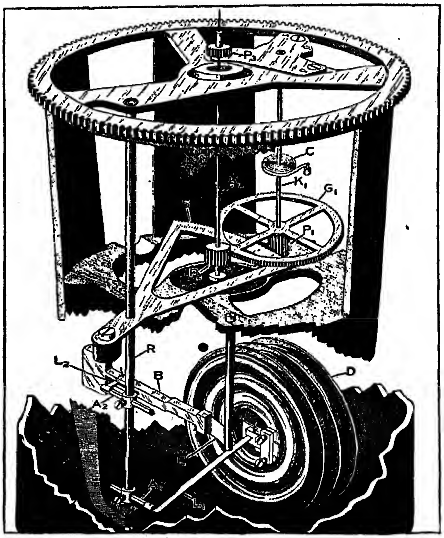


FIG. 2.—Diaphragm and lower gearing of Kollsman sensitive altimeter.

against one another, back to the diaphragms. Gear G_1 is fixed on shaft K_1 and is turned with it, turning pinion P_2, which is fixed on handstaff K_2, as is pinion P_3. The balance arm B is fixed to the frame through spring E. Connection to the rocking shaft R is made by link L_2 and arm A_2.

The long hand H_1 (Fig. 3) is on the end of handstaff K_2. Pinion P_3, which is on handstaff K_2, is turned with it, turning gear G_2 and staff K_3. Pinion P_4 is fixed on shaft K_3 and is turned with it, turning gear G_3 which is fixed to the hollow handstaff K_4. The short hand H_2 is fixed to the outer end of staff K_4. The relation of the pinion P_3, gear G_2, pinion P_4, and Gear G_3 is such that gear G_3 makes one-tenth of a turn when pinion P_3 makes one turn. In this way, the short hand H_2 makes one-tenth of a turn while the long hand H_1 is making one complete turn. The hands give the reading of altitude on dial D_1.

The adjustment for barometric pressure is made by turning the knob N, which is fixed on stem M. Pinion Q_1 is fixed on stem M and is turned by it, turning the complete mechanism through ring gear F_1, and turning the barometric scale D_2 through gear F_2, pinion Q_2 and ring gear F_3. The barometric scale gives the reading of barometric pressure through the window W in dial D_1.

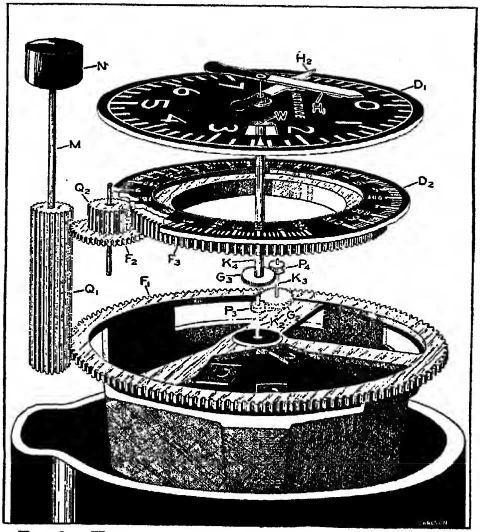


FIG. 3.—Upper works and dial of sensitive altimeter.

Repair and Adjustment.—To take apart, remove the outer snap ring, put a small screw driver or knife blade under one end of the ring, and lift it out. Use a suction cup to remove the glass. If the glass is tight, tap gently around the edge of the case (Fig. 4).

Use a watchmaker's hand puller to take off the hand, taking care to prevent damage to it or the staff. Take out the rubber ring and seating ring. These can be pulled loose from the wall of the case with the fingers and will come out if the instrument is turned upside down.

If the instrument is turned upside down, the dial, spring ring, and mechanism will come out. The barometric dial is fixed to the mechanism and there is no need to take it off. Use care in taking out the handstaff through the mechanism plate. The complete mechanism is seen in Fig. 5.

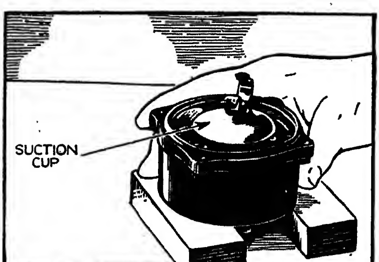


FIG. 4.—Suction cup for removing glass.

Taking the Mechanism Apart. Take out the small bearing that holds the end of the link to the adjustment arm. This frees the link from the arm as in Fig. 6. Do not touch the screw holding the arm in position.

Take the pivot screw out *part way* and remove the rocking-shaft assembly. Take out the plate screws and remove the lower plate. Take out the hairspring pin and handstaff assembly with the pinion, hairspring, and hairspring disk.

The parts of type 126 altimeter are shown in Fig. 7; those of type 127 in Fig. 8. The parts are: outer snap ring: glass; hand; rubber ring and seating

ring; inner snap ring; dial; spring ring; mechanism assembly; case and nipple union connection. They are quite similar. The parts seen in Fig. 9 are: frame unit with barometric dial; bearing pin; rocking-shaft unit with sector; plate screws; lower plate; handstaff unit; and the taper hairspring pin.

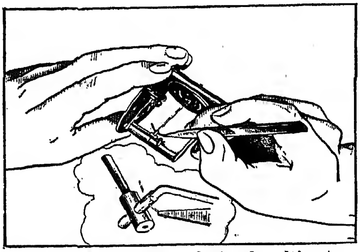


FIG. 5.—Mechanism of simple altimeter.

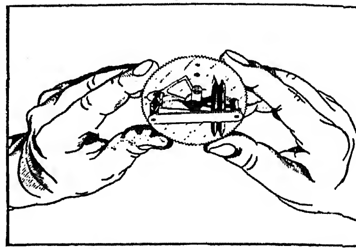


FIG. 6.—Freeing the link from the ar

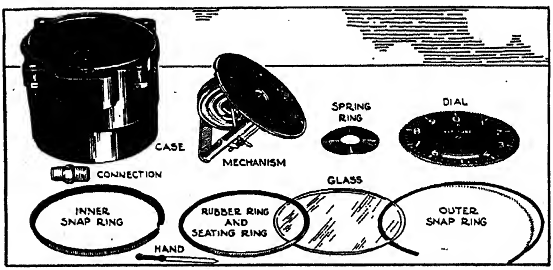


FIG. 7.—Parts of No. 126 altimeter.

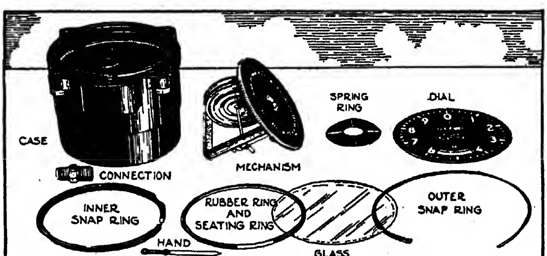


FIG. 8.—Parts of No. 127 altimeter.

It is not often necessary to take the rest of the mechanism apart. Should it be necessary, however, take off the small snap ring on the lower part of the pinion. It can be pushed out of place with a small screw driver. Push the small pin *part way* out of the pinion. The pin can be pulled out if the knob is given a half turn. The stem can then be pulled out of the case.

Parts of the knob stem unit shown in Fig. 10 are the adjustment knob stem, with knob and lock nut; washer; spring; pinion; pin; and snap ring.

All parts should be inspected; if any are worn or damaged, they should be replaced.

Cleaning Instruments.—All parts that have been removed should be put in a cup or glass of benzene, as in Fig. 11. The handstaff with pinion,

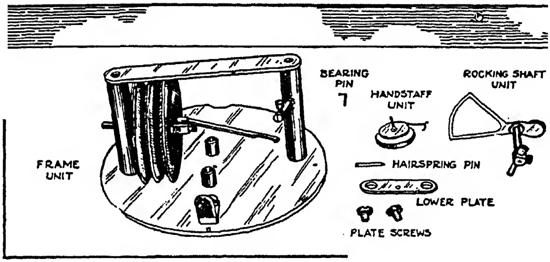


FIG. 9.—Frame unit with parts.

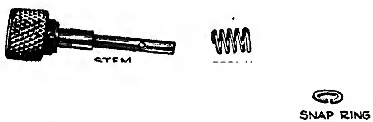


FIG. 10.—Knob, spring, and pinion.

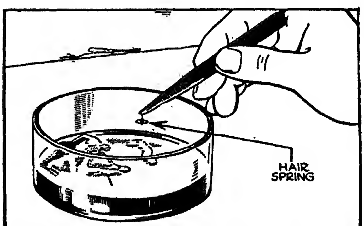


FIG. 11.—Handling hairspring in benzene bath.

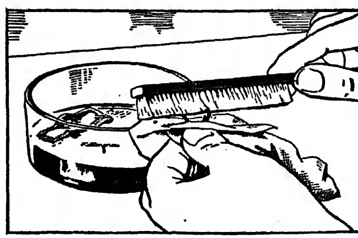


FIG. 12.—Cleaning gear teeth with a brush.

hairspring, and disk should be *put in last* and *taken out first*, to prevent damage by other parts.

Dry the hairspring with low-pressure air. Dry the other parts with a *clean* cloth, free from any bits of loose material. The pinion teeth and the sector, can be best cleaned with a brush, as in Fig. 12. Use an orange wood pin for cleaning all holes.

After the parts have been cleaned, inspect them again with a magnifying glass to be sure they are right. Should new parts be necessary, check them for balance after they are put in place.

Putting Instruments Together.—Assembling is the reverse of taking the instrument apart. Put the rocking-shaft unit in place, screwing in the pivot screw enough to keep it there. Put the bearing pin in place, making the connection between the link and arm. Then loosen the pivot screw and let the sector come out of the mesh with the pinion.

With the mechanism held as in Fig. 13, move the hairspring 2½ turns to the left, to tighten it or give it more tension. Keep the hand in this position and push the sector into mesh with the pinion (Fig. 14). Tighten the pivot screw to keep the working shaft and sector in place. Adjustment

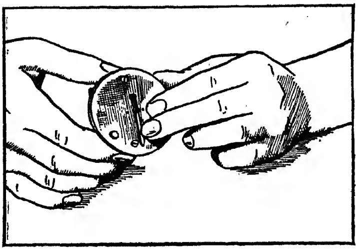


FIG. 13.—Putting tension on hair spring.

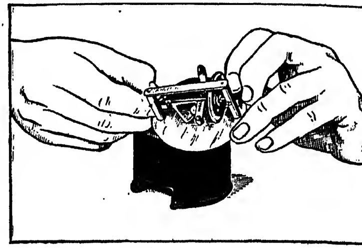


FIG. 14.—Meshing pinion and sector.

of the pivot screw gives the rocking shaft the right amount of play. Test the mechanism before it is put back in the case.

Testing the Instrument.—A special testing frame, such as Fig. 15, is needed for adjustments. This frame has collars for keeping the mechanism in place and a dial that may be turned to any reading. Put the mechanism in the test frame and put on the hand. Turn the dial until the hand is at the same reading as the standard altimeter, or mercury barometer, used for test. Put the mechanism, in the test frame, in a bell jar, or test box.

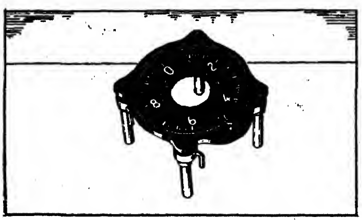


FIG. 15.—Kollsman test frame.

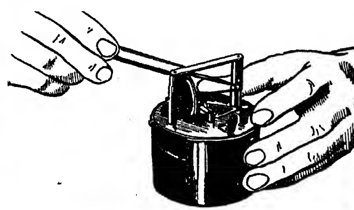


FIG. 16.—Correcting the adjustment.

Make scale error, hysteresis, and friction tests. If errors are within the limits of Table 3, the instrument can be put in its case.

If Adjustment Is Needed.—If the hand did not come to the highest scale mark within the limit, *the range is not right.* If it came to the mark within the limit but was outside the limits at points in the middle of the scale, *the range is right but the adjustment* is wrong. The range is changed by changing the length of the adjustment arm *A*. To do this, take out the adjustment screw *part way* (Fig. 16). To *increase the range* make the arm *shorter;* to *decrease* it, make the arm *longer.*

After getting the hand to come to the highest scale mark within the limit, see if the middle scale readings are right. If not, adjust the position of the diaphragm unit (Fig. 17). Take the diaphragm-post screw out *part way*. Move the diaphragm unit *away* from the post to make the mid-scale readings *greater;* move it *toward* the post to make the mid-scale readings *smaller*.

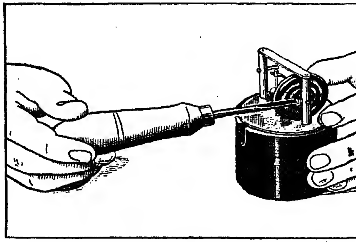


Fig. 17.—Adjusting diaphragm unit.

Since changing the position of the diaphragm unit affects the range as well, the position of the adjustment arm will have to be changed to get it in range again.

Putting Mechanism Back in Case.—After the test shows the instrument to be right, put it in the case in reverse order from that used in taking it out. Before putting on the hands, turn the adjustment knob until the reading on the barometric dial corresponds with the barometer or standard altimeter. Then put the hand in place so that it reads "zero." Put in the seating ring and the rubber ring. Put the glass on top of the rubber ring and put the outer snap ring in place.

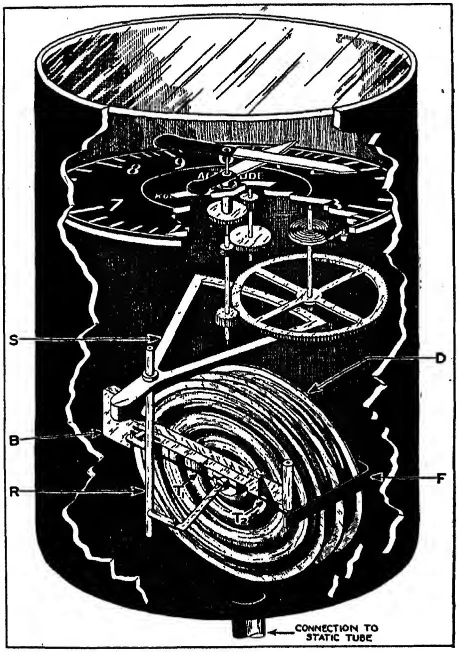


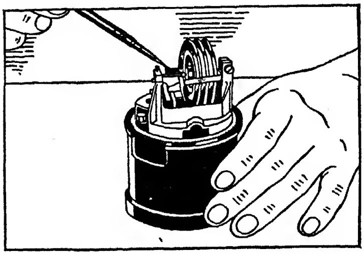
Fig. 18.—Temperature compensation on sensitive altimeter.

Use a new rubber ring if possible. If not, and if the old ring does not make the case tight, use plasteline, or some such plastic material, around the edge of the glass.

Disassembly of Sensitive Altimeters.—The sensitive altimeter shown in Fig. 2 does not have full-range compensation. The temperature compensation unit is fixed to the diaphragm unit by two screws, which should not be touched. Full-range compensation is shown in Fig. 18. Here the temperature compensation unit is in the form of a fork F around the diaphragm unit. It connects to the diaphragm by pins T_1 and T_2. No parts of the temperature compensation unit should be touched or changed in any way.

It is specially important that the pins indicated in Fig. 19 *and the nuts pointed out in Fig.* 20 *should not be moved, on all Kollsman sensitive altimeters.*

First remove the bearing pin between the balance arm link and the second adjustment arm on the rocking shaft (Fig. 21). Do this before removing



. 19.—Do not remove pins shown here.

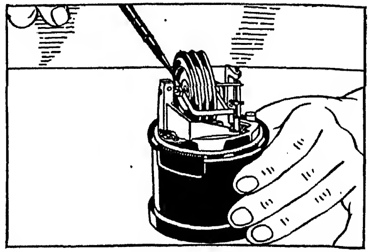
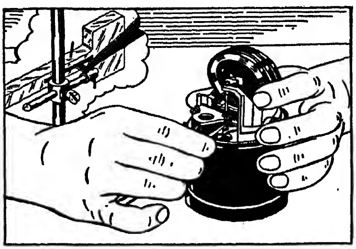


FIG. 20.—These nuts should not be removed.



G. 21.—Removing the bearing pin.

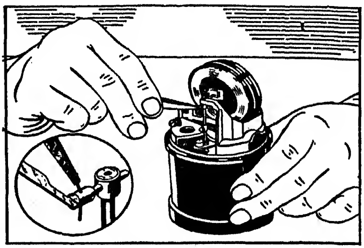


FIG. 22.—Taking out another bearing pin.

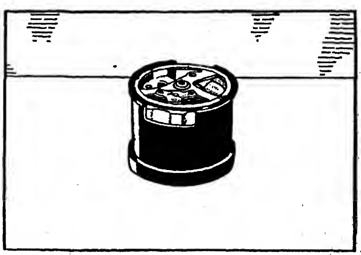


FIG. 23.—Special support for holding mechanism.

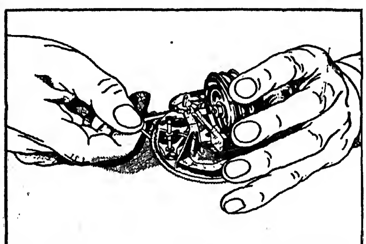


FIG. 24.—Pulling out rocking shaft unit.

any other parts to take the tension off the gear train. Take out the bearing pin between the diaphragm link and the first adjustment arm on the rocking-shaft unit (Fig. 22); then put the mechanism in the support shown in Fig. 23.

Take the pinion off the handstaff with a special pinion puller. Take the jewel screw out *part way*. Put the finger or thumb against the side of the

sector to keep it from moving; then push out the handstaff and jewel unit. The parts taken out are the center pinion, the handstaff with its pinion, and the jewel unit. Take the rocking-shaft pivot screw out part way.

In the sensitive altimeters of 20,000-ft. range the rocking shaft can be pulled straight out. In the 35,000-ft. range, take the rocking-shaft pivot screw out part way. The rocking-shaft unit is not pulled straight out but is turned so the sector goes down through the hole in the frame; it is pulled out by the sector through the hole in the frame (Fig. 24).

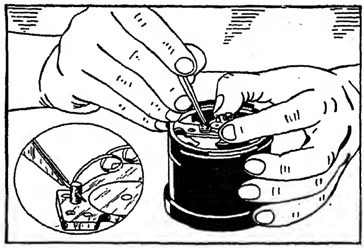


Fig. 25.—Removing the hair

In all Kollsman altimeters, take out the three bearing plate screws and lift out the bearing plate *very carefully*, as the hairspring is fastened to it. Turn the bearing plate over, push the hairspring free, and remove it as in Fig. 25. Lift the wheel through the hole in the site of the mechanism frame with tweezers.

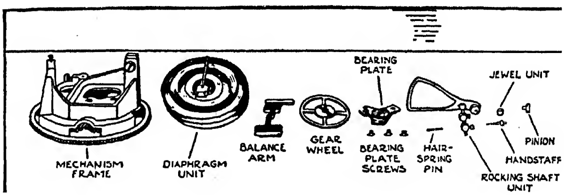


Fig. 26.—Parts of the unit.

If the balance arm has been damaged, take out the arm screw part way and remove the arm; otherwise, do not remove it. The same holds true for the diaphragm unit. The parts of the unit are seen in Fig. 26. They are the center pinion; handstaff with its pinion, jewel unit; rocking-shaft unit; bearing plate; bearing plate screws; hairspring pin; gear wheel with hairspring assembly; balance arm; diaphragm unit; and mechanism frame.

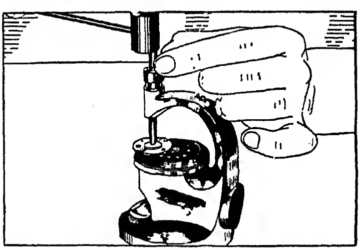


Fig. 27.—Forcing bushing out of small gear.

To take the gear unit apart, first take out the three screws in the cover plate and remove the plate. The small pinion and gear are then removed with tweezers. Use a small arbor press (Fig. 27) to remove the bushing from the small gear. The parts of the gear unit (Fig. 28) are the frame; cover plate; middle gear; short hand gear; cover plate screws; and bushing for the short hand.

The parts of the gear unit of the Kollsman sensitive altimeter with three hands are seen in Fig. 29. These are the frame; cover plate and screws;

short handstaff; middle gear unit; 40-tooth gear unit; 39-tooth gear unit; third hand pinion; and third hand gear.

Among the items to be checked are too much play; bent parts; broken pivots; bent handstaffs; side play; corrosion; broken jewels; worn-out pivot holes; worn-out pivots; rusty pinion teeth; worn-out gear teeth; wheels out of true; moving parts out of balance; and dented diaphragms. Each of these defects requires careful treatment, according to directions given by the Kollsman Co.

Suggestions for Taking Apart.—Broken cases and glasses that are marked or cracked are not to be used again. Rubber rings, if hard and no longer

FIG. 28.—Parts of small gear assembly.

elastic, are not to be used. Pressure connections and other parts (such as lug inserts) must not be used if their threads are badly worn or if there is much corrosion on them. Screws with poor threads are not to be used; put in new ones.

Taking Out Tight Glasses.—Glasses that are so tight in the instrument case that they cannot be pulled out with a suction cup may usually be forced out by air pressure. *Air pressure is not to be used in taking glasses out of vertical speed indicators*, as the instrument will be damaged by the use of such high pressure.

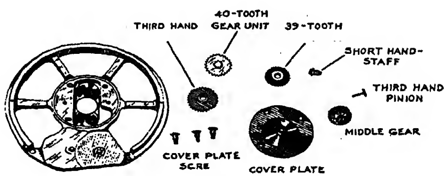


FIG. 29.—Gear train for Kollsman sensitive altimeter.

Air pressure may not be used in taking glasses out of the cases of clocks, pressure gages, thermometers, or manifold pressure gages of the vacuum cartridge type, as these instruments have no connection from the outside to the inside of the case.

On instruments that have two connections, one to the inside of the diaphragm and the other to the inside of the case (for example, air speed indicators), the pressure inside and outside of the diaphragm may be kept equal by using a T connection and so putting the same pressure in the diaphragm as in the case.

Great care must be used in forcing out glasses by air pressure, so that no damage is done to instrument diaphragms. Do not make use of pressures

greater than 10 lb. per sq. in. If the glass will not come out with this pressure, put a suction cup on the glass, pulling on the cup at the same time as pressure is put on the inside of the case.

If the glass can be got out in no other way, it may be broken. When this is necessary, it must be done with great care, so that no bits of glass get into the mechanism.

Cleaning.—If at all possible, tarnished parts, especially the teeth of pinions and small gears, are to be cleaned, not only on account of the looks but because the motion of the instrument pointer will be smoother if there is no tarnish on the gear teeth.

Tarnish may be taken off easily in a bath of potassium or sodium cyanide made with 8 oz. per gal. of water. Before being put in the cyanide, the parts are to be freed from oil or grease by putting them in a cleaner such as benzene, carbon tetrachloride, or trichloroethylene. After cleaning, they are to be dried and then put for a few seconds in the cyanide bath, then in cold water, and, last, in hot water for quick drying. Parts may be dried with a soft cloth which is free from bits of loose material, but they may be dried better and quicker by shaking the parts in a box half-full of hardwood sawdust.

Cyanides are deadly poisons and are to be used with great care. See that no drop of cyanide gets on the hands. The parts are to be lowered into the bath in a small wire basket or on a wire.

In place of the cyanide bath a cleaner may be made from these materials (parts are given by weight):

Water	100
Oxalic acid	4
Alcohol	25
Ammonia	12
Castile soap	17

After using this cleaner, all parts are to be washed in cold and hot water and dried as when cyanide is used.

After the parts are taken out of the sawdust, they are to be brushed with a No. 3 watchmaker's brush which is rubbed from time to time on a cake of prepared chalk. The parts are not to be held in the bare hand, but a sheet of watch paper (hard thin paper made specially for this purpose) is to be put between the fingers and the part.

The teeth of pinions and gears are to be brushed with short motions from side to side across them.

After brushing, the parts are to be looked over with a magnifying glass to make certain that they are truly clean, and then placed at once under one of the small bell jars where they are to be kept ready for putting together.

All the pivot holes are to be cleaned with care, using the pointed end of an orangewood (pegwood) stick, which is to be scraped clean frequently. A last touch in the cleaning of pivots is sticking them into dry elder pith.

When the last parts are ready, all parts having been put under cover as soon as they were cleaned, they are to be put together quickly.

If the repair is such that the instrument is in need of a complete new adjustment, it is better to put the instrument together after a rough cleaning in benzene or similar liquid and make the adjustment; then take the instrument apart once more, or at least the gear train, give it a complete cleaning and put it together again, to be sure that there is the least possible dust when it is put back in its case.

Use no oil on delicate instruments except on the ball bearings. Oil usually thickens at low temperatures and affects the proper operation.

REPAIRING AIRPLANE INSTRUMENTS

Repairing airplane instruments is much like repairing watches; the same sort of workroom and workmanship is needed. Good light is necessary, but it is best to have it come from the north so that changes in temperature will not be great. It is specially important to keep out dust, moisture, and gases of all sorts that may be the cause of corrosion.

The workbench (or table) should be placed in front of a window. It may be made like a watch repair bench, but larger. The top is to be of wood or linoleum, made smooth and level so that parts may be placed on it without danger of their rolling off or falling into a crack. At the back of the bench and at the two sides are boards about 6 in. high with no cracks between the bench top and the side boards. It is a good idea to put a board at the front of the bench, forming an edge about $\frac{1}{4}$ in. high, to keep small parts

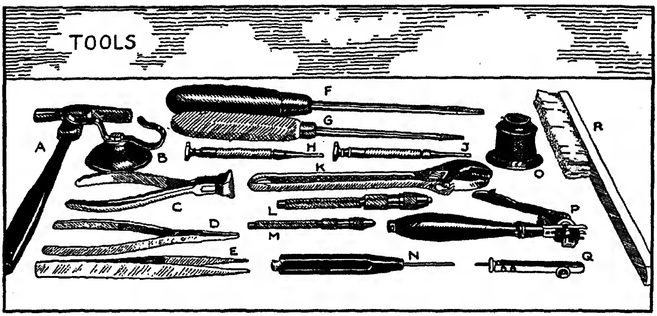


Fig. 30.—Tools used in instrument repair.

from being pushed off. Loss of parts while an instrument is being repaired is frequently the cause of much trouble, for new parts are sometimes very hard to get. To keep parts from falling on the floor, it is wise to make a frame that may be slipped under the bench like a drawer, the front part of the frame being curved and its top covered with canvas or other cloth. If this frame is pulled out against the worker's body, any parts that get away from fingers or tweezers will be dropped on the cloth and not on the floor.

A good workbench has a number of drawers for keeping tools. Drawers with divisions in which every tool has its special place are of great help to a repair man, and it is not then necessary to have many tools on the bench where they may get in the way.

Tools.—Hand tools needed by every airplane instrument repair man are seen in Fig. 30. They are:

A—Hammer
B—Suction cup
C—Cutting pliers
D—Flat-nose pliers
E—Tweezers
F, *G*, *H*, and *J*—Screw drivers
K—Wrench
L and *M*—Pin vises
N—Setscrew wrench
O—Magnifying glass or loupe
P and *Q*—Hand pullers
R—Brush

In addition to the tools shown in Fig. 30, a man who is to do much instrument repair work will have need of the following:

1. A watchmaker's vise, having jaws 1 to 1½ in. wide.
2. A watchmaker's lathe.
3. A staking tool (or arbor press) for taking out staffs and hubs and putting them back in again.
4. Truing calipers for testing wheels on their staffs to see that they are round and true.
5. A balancing (or poising) tool which has two parallel knife-edges on a support. The pivots of parts to be balanced may be rested on these knife-edges with almost no friction.
6. Glass vessels with covers, for cleaning liquids.
7. Glass covers (bell jars) of different sizes to keep parts and complete mechanisms covered when they are not being worked on.
8. Rubber tubing for making connections to the instruments, with some tubes long enough to be used in roller pumps.
9. Roller pumps. These are very good for making small changes in pressure while testing an instrument.
10. Electric buzzer. Instruments are to be tapped or lightly hammered while being tested, to take out any friction. It is better to make use of an electric buzzer than to do this tapping by hand. A good electric shaking apparatus may be made from a simple electric buzzer or doorbell. The buzzer may be fixed to the board or other support for the instrument to be tested. The amount of hammering effect may be changed by putting more or less weight on the arm of the buzzer.
11. Broaches for sizing and polishing pivot holes. Some of the smallest sizes of clock broaches and the largest sizes of watch broaches will be needed; in addition, some polishing (or burnishing) broaches, which are long needles having a high polish, and some small countersinks for taking off burrs after broaching. A good form of countersink which is used by watchmakers has very small wheels at the ends of a handle like that of a watchmaker's screw driver.
12. Pivot burnishers with square shoulders.
13. Oilstone slips of different fineness, the finest of all being jasper.
14. Polishing materials, such as aluminum oxide (levigated alumina) or rouge, and some square boxwood slips with which to do the polishing.
15. Sticks of orangewood (pegwood) which, when pointed up with a knife, are very good for cleaning pivot holes.
16. Watch papers as used by watchmakers. These are squares of strong thin paper which are put between the hand and the part to be cleaned during the brushing operation.
17. Prepared chalk, as used by watchmakers, to be used on the brush when cleaning parts.
18. Glass funnel and filter paper to be used in cleaning compass liquid.
19. Radium luminous material and adhesive, thinner, fine-pointed sable brushes, small crucible for mixing radium paint, and a small spatula for scraping it.
20. Some elder pith for cleaning small parts.

General Directions.—Electric and other connections give more trouble than the instruments themselves. All electric wires, pipe connections, and outside details should be checked carefully before taking an instrument from the plane. Tightening a loose connection often remedies an apparent trouble with instruments. If an instrument has been dropped or seriously jarred, it should be tested. If only normal errors show up, it is probably all right; if errors are too large, it needs repair.

Do not blow in the connection of any instrument. It may cause serious damage. Either pressure or moisture may injure it. When instruments have aluminum connections, use a "non-seize" paste on all threads.

Before Taking Apart.—Before taking any mechanism apart, examine it carefully. Troubles are often seen more clearly in a complete mechanism than when it is disassembled.

Test the play in bearings with tweezers and watch it with a good magnifying glass. You can "feel" movement more easily than you can see it. Where much play is found, it should be recorded before putting the mechanism together.

While checking the mechanism, look for corrosion, bent, broken, or worn parts, screws with poor threads, or any sign of damage. Special attention should be given to the parts with relation to each so as to save time in reassembly.

Arrange the screws and other parts in an orderly way so that every part can be easily found and put back where it belongs. If all screws are not of the same length, note where each one goes.

Check the separate parts for broken jewels; worn pivot holes; worn, bent, or rusty pivots; worn, bent, or rusty pinion or gear teeth; wheels out of

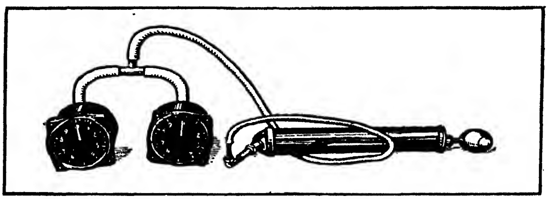


Fig. 31.—Air pump for testing with standard instrument.

round or bent; moving parts out of balance; damaged diaphragms; bad radium paint; trouble with case, glass, rubber ring, or pressure connection. Make all repairs before the final cleaning. This greatly reduces the chance of getting dust into the mechanism.

Apparatus for Tests on Airplane.—Test material, shown in Fig. 31, consists of a hand-worked vacuum pump;[1] three rubber tubes with a T connection; and a specially tested altimeter as a standard.[2]

It is important that the connection tube from the altimeter to the Pitot-static tube is airtight. Directions for testing this tube line are given under Air Speed Indicator, page 563.

The case of the altimeter is to be tested to see that it is airtight. Directions for making this test also are given under Air Speed Indicator.

If the case is seen to be airtight within the limit, the altimeter should be tested for scale error. Connection is to be made from the pump, through the rubber tubes and T connection, to the altimeter on the airplane and to the standard test altimeter.

[1] The hand pump used for testing manifold pressure gages may be used for testing altimeters.

[2] The relation between altitude and pressure is based upon one of two standards: The United States (U.S.) or the Federation Aeronautique Internationale (F.A.I). The standard of the International Commission for Air Navigation (I.C.A.N.), used in most countries, is the same as the U.S. Standard. Table 1 on pages 557 and 558 is based on the U.S. Standard. A comparison of the U.S. and F.A.I. Standards is given in Table 2.

Table 1.—Altitudes, Pressures, and Temperatures
(Based on U.S. Standard)

Ft.	In., Hg	Air temperature, °F.	Air temperature, °C.	Mean temperature, °F.	Mean temperature, °C.
− 1,640.4		+65.0	+18.3	+61.9	+16.6
− 1,000	31.02	62.6	17.0	60.8	16.0
0	29.92	59.0	15.0	59.0	15.0
+ 1,000	28.86	55.4	13.0	57.2	14.0
1,640.4		53.1	11.7	56.1	13.4
2,000	27.82	51.8	11.0	55.4	13.0
3,000	26.81	48.4	9.1	53.6	12.0
3,280.8		47.3	8.5	53.1	11.7
4,000	25.84	44.8	7.1	51.8	11.0
4,921.2		41.4	5.2	50.2	10.1
5,000	24.89	41.2	5.1	50.0	10.0
6,000	23.98	37.6	3.1	48.2	9.0
6,561.7		35.6	2.0	47.1	8.4
7,000	23.09	34.0	+ 1.1	46.4	8.0
8,000	22.22	30.6	− 0.8	44.6	7.0
8,202.1		29.8	− 1.2	44.2	6.8
9,000	21.38	27.0	− 2.8	42.8	6.0
9,842.5		23.9	− 4.5	41.4	5.2
10,000	20.58	23.4	− 4.8	41.0	5.0
11,000	19.79	19.8	− 6.8	39.2	4.0
11,483		18.0	− 7.8	38.3	3.5
12,000	19.03	16.2	− 8.8	37.2	2.9
13,000	18.29	12.6	−10.8	35.4	1.9
13,123		12.2	−11.0	35.2	1.8
14,000	17.57	9.1	−12.7	33.6	0.9
14,764		7.6	−14.2	32.2	+ 0.1
15,000	16.88	5.5	−14.7	31.8	− 0.1
16,000	16.21	1.9	−16.7	29.8	− 1.2
16,404		+ 0.5	−17.5	29.2	− 1.6
17,000	15.56	− 1.7	−18.7	28.0	− 2.2
18,000	14.94	− 5.3	−20.7	26.2	− 3.2
18,045		− 5.4	−20.8	26.1	− 3.3
19,000	14.33	− 8.7	−22.6	25.7	− 4.3
19,685		−11.2	−24.0	23.0	− 5.0
20,000	13.75	−12.3	−24.6	22.5	− 5.3
21,000	13.18	−15.9	−26.6	20.7	− 6.3
21,325		−17.1	−27.3	19.9	− 6.7
22,000	12.63	−19.5	−28.6	18.7	− 7.4
22,966		−22.9	−30.5	16.9	− 8.4
23,000	12.10	−23.1	−30.6	16.9	− 8.4
24,000	11.59	−26.5	−32.5	14.9	− 9.5
24,606		−28.7	−33.7	13.8	−10.1
25,000	11.10	−30.1	−34.5	13.1	−10.5
26,000	10.62	−33.7	−36.5	+11.1	−11.6
26,247		−34.6	−37.0	10.6	−11.9
27,000	10.16	−37.3	−38.5	9.1	−12.7
27,887		−40.5	−40.3	7.5	−13.6
28,000	9.72	−40.9	−40.5	7.3	−13.7
29,000	9.29	−44.5	−42.5	5.4	−14.8
29,528		−47.0	−43.5	4.3	−15.4
30,000	8.88	−47.9	−44.4	3.4	−15.9
31,000	8.48	−53.5	−46.4	1.6	−16.9
31,168		−54.1	−46.7	+ 1.2	−17.1
32,000	8.10	−55.1	−48.4	− 0.4	−18.0
32,808		−58.0	−50.0	− 2.0	−18.9
33,000	7.73	−58.7	−50.4	− 2.0	−19.1
34,000	7.38	−62.3	−52.4	− 4.4	−20.2
34,449		−63.9	−53.3	− 5.3	−20.7
35,000	7.04	−65.7	−54.3	− 6.3	−21.3
36,000	6.71	−67.0	−55.0	− 8.1	−22.3

1.—**Altitudes, Pressures, and Temperatures** (*Continued*)

Ft.	In., Hg	Air temperature, °F.	Air temperature, °C.	Mean temperature, °F.	Mean temperature, °C.
36,089		−67.0	−55.0	− 8.3	−22.4
37,000	6.39	−67.0	−55.0	− 9.9	−23.3
37,730		−67.0	−55.0	−11.2	−24.0
38,000	6.10	−67.0	−55.0	−11.7	−24.3
39,000	5.81	−67.0	−55.0	−13.4	−25.2
39,370		−67.0	−55.0	−13.4	−25.2
40,000	5.54	−67.0	−55.0	−14.8	−26.0
41,000	5.28	−67.0	−55.0	−16.2	−26.8
41,010		−67.0	−55.0	−16.2	−26.8
42,000	5.04	−67.0	−55.0	−17.7	−27.6
42,651		−67.0	−55.0	−18.8	−28.2
43,000	4.80	−67.0	−55.0	−18.9	−28.3
44,000	4.58	−67.0	−55.0	−20.2	−29.0
44,291		−67.0	−55.0	−20.7	−29.2
45,000	4.36	−67.0	−55.0	−21.3	−29.6
45,932		−67.0	−55.0	−22.4	−30.2
46,000	4.16	−67.0	−55.0	−22.4	−30.2
47,000	3.97	−67.0	−55.0	−23.4	−30.8
47,572		−67.0	−55.0	−24.2	−31.2
48,000	3.781	−67.0	−55.0	−24.5	−31.4
49,000	3.605	−67.0	−55.0	−25.4	−31.9
49,212		−67.0	−55.0	−25.4	−31.9
50,000	3.436	−67.0	−55.0	−25.6	−32.0

This test is the same as that to be made later in the workroom, and it is not necessary for it to be made on the airplane if the instrument is to be taken off. Directions for making this scale error test are given under Tests.

An altimeter is not, however, to be tested in this way to altitudes higher than 25,000 ft.

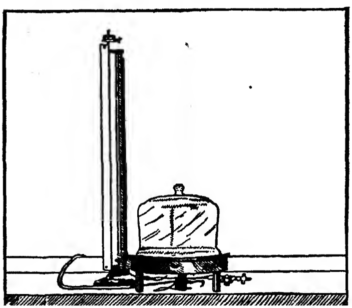


FIG. 32.—Kollsman testing apparatus.

Apparatus for Tests in Workroom. The Kollsman altimeter test stand is seen in Fig. 32. It has a bell jar and base, a pump, a standard altimeter, and a mercury barometer. The Kollsman manifold pressure gage test stand may also be used for testing altimeters.

Tests. *Scale and Hysteresis Errors.* The altimeter to be tested is placed in its normal upright position in the bell jar or test box. The connection to the pump is opened and the pressure lowered to the test points given in Table 3, page 560, one after the other. The pressure is to be lowered at the rate of about 3,000 ft. per min. and kept at a fixed value for not less than 1 min. (or more than 10 min.) at the test point. Before taking the reading, the test box or the bell-jar base is to be tapped hard enough to give an effect

equal to a light tap on the instrument. When the pressure has been lowered to give the highest reading on the instrument dial, let it go back up, taking readings again at the hysteresis test points given in Table 3. The amounts by which the readings were different going up and coming down are measures of the hysteresis. Limits for scale and hysteresis errors are given in Table 3.

Aftereffect Test.—At the end of the scale error and hysteresis tests (not less than 1 min. nor more than 5 min. after) the reading of the altimeter is to be noted. The amount by which this reading may be different from the first reading at zero altitude (after taking account of any change in the outside pressure) is given as the limit of aftereffect error in Table 3.

Friction Error.—At every test point marked with a star in Table 3, take two readings, the first without tapping the bell-jar base; then, without changing the pressure, after tapping the bell-jar base. The amount by which the second reading is different from the first reading is the friction error. Limits are given in Table 3. See, in addition, that the motion of the hand is smooth as the pressure goes up or down.

Barometric corrections are given in Table 4.

Position Error.—To make the test for position error, turn the instrument from its normal upright position through 90 deg. forward and back and left and right. At every different position of the instrument, make a note of its reading after tapping lightly. The amount by which these readings may be different from those in the normal upright position is given in Table 3 as the limit of position error.

Table 2.—Comparison of U.S. and F.A.I. Standards

Altitude		Pressure
U.S. meters	F.A.I. meters	Mm. Hg at 0°C.
0	0	760.0
500	484	716.0
518	500	714.5
1,000	973	674.1
1,029	1,000	671.7
1,500	1,461	634.2
1,540	1,500	631.1
2,000	1,952	596.2
2,049	2,000	592.6
2,500	2,445	560.1
2,557	2,500	556.1
3,000	2,936	525.8
3,066	3,000	521.4
3,500	3,427	493.2
3,574	3,500	488.5
4,000	3,919	462.2
4,084	4,000	457.2
4,500	4,408	432.9
4,595	4,500	427.5
5,000	4,897	405.1
5,105	5,000	399.4
5,500	5,387	378.7
5,616	5,500	372.8
6,000	5,875	353.8
6,128	6,000	347.6
6,500	6,364	330.2
6,640	6,500	323.8
7,000	6,854	307.8
7,150	7,000	301.4
7,500	7,343	286.8
7,660	7,500	280.3
8,000	7,834	266.9
8,170	8,000	260.4
8,500	8,327	248.1
8,679	8,500	241.7
9,000	8,819	230.5
9,181	9,000	224.3
9,500	9,318	213.8
9,682	9,500	208.0
10,000	9,817	198.2
10,182	10,000	192.7

Low Temperature Test.—If the altimeter is to be used at low temperature, it is to be tested for scale errors at low temperature. The test is the same as that for scale error, but at a temperature of −31°F. Tests are to be made at the test points indicated in Table 3. The reading at any test point may be different from the reading at the same test point at normal

Table 3.—Common Ranges, Test Points, and Limits

Simple altimeters		Sensitive altimeters		
Test point, ft.	Scale error limit, ft.	Test point, ft.	Scale error limit, ft.	Temperature error limit* ft.
0	100†	0	50*	40
2,000	100	2,000	100	
4,000	100	4,000	100	
6,000	200†	6,000	100†	70
8,000	200	8,000	150	
10,000§	200	10,000§	150	
12,000‡	200†	12,000‡	200†	90
14,000	300	14,000	200	
16,000¶	300	16,000¶	200	
18,000‖	300†	18,000‖	200†	125
20,000	300	20,000	200	
22,000	400	22,000	300	
24,000	500†	24,000	300†	175
28,000	600	28,000	300	
32,000	700	32,000	300	
35,000	800†	35,000	300†	250

Error	Limit, ft.	Error	Limit, ft.
Hysteresis	140	Hysteresis	70
Aftereffect	80	Aftereffect	50
Position	200	Position	20
Friction	200	Friction	100
Temperature:		Vibration:	
Average change	500	Hand motion	20
Change at 0	150	Zero change	50
Vibration:			
Hand motion	200		
Zero change	70		

Hysteresis test points:
* For altimeters with full-range compensation.
† For certain tests.
‡ First test point, 20,000-ft. range.
§ Second test point, 20,000-ft. range.
‖ First test point, 35,000-ft. range.
¶ Second test point, 35,000-ft. range.

Table 4.—Barometer Corrections

Temperature		Correction	
°F.	°C.	Hg with brass	Hg with aluminum
32	0	−.0004	−.0005
40	4.44	−.0011	−.0012
41	5	−.0012	−.0013
50	10	−.0020	−.0021
59	15	−.0028	−.0028
60	15.56	−.0029	−.0029
68	20	−.0036	−.0036
70	21.11	−.0038	−.0038
77	25	−.0044	−.0044
80	26.67	−.0047	−.0047
86	30	−.0052	−.0052
90	32.22	−.0056	−.0055
95	35	−.0061	−.0060

temperature by the amounts given in Table 5. For altimeters without full-range temperature compensation, take the values given for simple altimeters; for altimeters with full-range compensation, take the value given for sensitive altimeters.

Vibration Test.—To make certain that the hand will not have any motion from side to side, and that the reading of the altimeter will not be changed when the instrument is under vibration on the airplane, it may be tested on a vibration test stand. Limits for hand motion and for zero change are given in Table 5. The limit for zero change is based upon vibration for 3 hr.

If the errors in any test are more than those given in Table 3, the instrument is in need of adjustment or repair.

However, even if there are no errors outside the limits, the instrument has to be taken apart and cleaned after about every 1,000 hr. of use.

AIR SPEED INDICATOR

The air speed indicator gives the speed of the airplane in relation to the air. It gives the *true air speed only at sea level.*[1] At any higher altitude it gives a speed less than the true air speed.[2] At all altitudes, however, the reading of the air speed indicator is a measure of the supporting force of the air. For example, if the lowest speed at which an airplane will keep in level flight at sea level is 40 miles per hr., it may be kept in level flight at any altitude at a reading of the air speed indicator of 40 miles per hr., even though it takes a much higher true air speed to give enough support in the thinner air at the higher altitude.

The air speed indicator is a pressure instrument. It is worked by the different pressures at the two openings of a Pitot-static tube. When air goes past a Pitot-static tube, its speed is changed into pressure at the Pitot opening, and the static opening is under the normal pressure of the air.[3] The Pitot-static tube is joined to the indicator by two metal pipes or tubes, with connection parts between units of tubing. There is a drain in every tube to let out water. On some airplanes other instruments (altimeter and vertical speed indicator) have connections to the same static tubing as the air speed indicator.

Mechanism.—An inside view, in simple form, of the air speed indicator is shown in Fig. 33. The Pitot connection goes to the inside of the diaphragm. The static connection goes to the inside of the case. This puts the two sides of the diaphragm under different pressures (Pitot pressure inside and static pressure outside), causing its expansion. The wire B and arm A_1 are lifted, turning the rocking shaft R. Arm A_2, which is a part of the rocking-shaft unit, is moved against arm A_3, which is fixed to the sector S, turning the sector and so turning the pinion P which is a part of the staff G. The hand H is on the staff G, as is the hairspring C. The force of this spring C keeps all parts tight against one another.

Apparatus for Tests on Airplane.—Simple test material is seen in Fig. 34, a T connection and three rubber tubes. Parts for covering the Pitot, static, and drain openings of the Pitot-static tube are needed in addition. For covering the Kollsman electrically heated Pitot-static tube, special

[1] The instrument is so made as to give true readings in air at normal pressure and temperature: 29.92 in. Hg, and 59°F.

[2] Scales for changing air speed readings to true air speed, at any altitude and temperature, are supplied by the Kollsman Company.

[3] The relation between speed and pressure is given in Table 6, page 568.

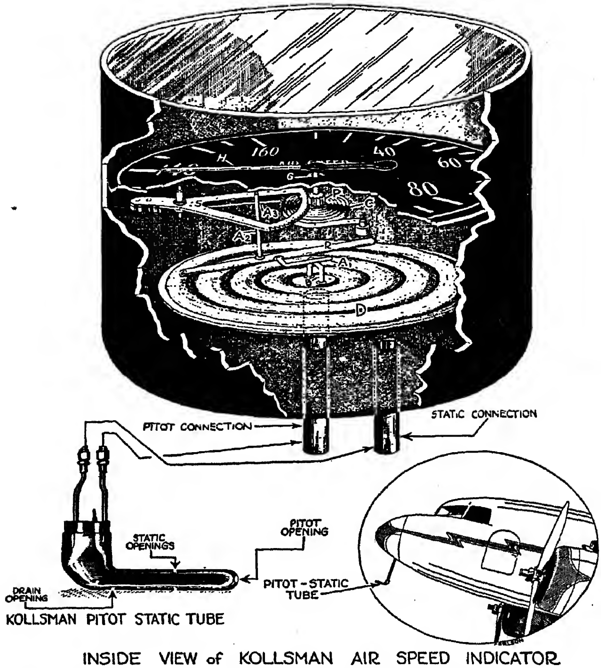


FIG. 33.—Kollsman air-speed indicator.

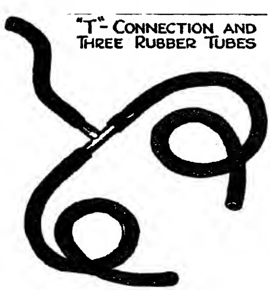


FIG. 34.—Hose and connections for testing.

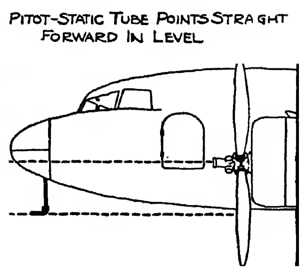


FIG. 35.—Location of Pitot-static tube.

parts are seen in Figs. 37 and 38. These are a Pitot cover and two elastic bands for covering the static and drain openings.

Tests on Airplane.—See that the Pitot-static tube is pointing straight forward, in line with the normal flight direction of the airplane (see Fig. 35). If it is not, it may be bent to the right direction.[1] If it is damaged in any way, especially near the static opening, take it off and put on a new tube. Take the tubes off the air speed indicator and, if there are connections from

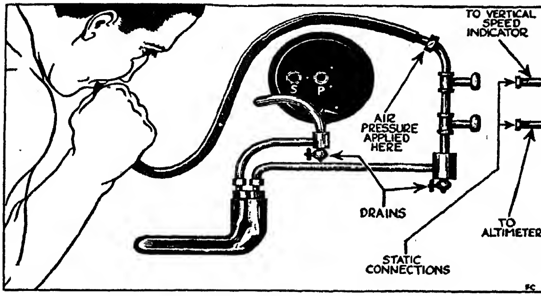


FIG. 36.—Clearing tubes by blowing.

the static tube to any other instrument, take off these connections. All but the opening of the static tube are to be shut off. Have the drains in the connection tubes open. With an air pump if possible (even a small tire pump is better than blowing with the mouth), air under pressure is to be forced through the connection tubes till all the water has come out (see Fig. 36). The drains are then to be shut off.

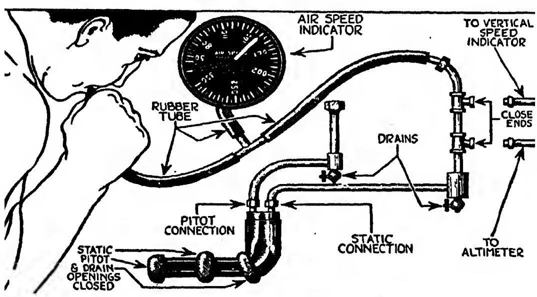


FIG. 37.—Another method of testing.

To See That the Pitot Connection Tubing Is Airtight.—All three Pitot-static tube openings—Pitot, static, and drain holes—are to be covered.

[1] To get the air speed indicator to give a higher reading, a ring is sometimes put on the static tube in front of the static openings. This makes the pressure lower at the static openings and has the same effect (on the air speed indicator) as higher air speed at the Pitot opening. If the static tube (of Pitot-static tubes having separate tubes) is bent, it gives the same effect. However, these changes in the static tube give serious errors in readings, not only of the air speed indicator but of the altimeter and vertical speed indicator as well.

Using the test material seen in Fig. 34, put one rubber tube on the Pitot connection of the air speed indicator, put one rubber tube on the end of the Pitot connection tubing, and put the third rubber tube in the mouth,[1] all three tubes being joined to the T connection (see Fig. 37). While watching the hand of the air-speed indicator, air is to be pumped or blown into the tube till the hand comes to about half scale. At that point the rubber

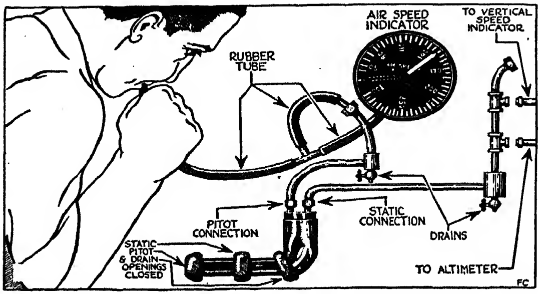


Fig. 38.—Testing static connections.

tube is to be shut off while still watching the hand of the air speed indicator. If the connection tubing is airtight, there will be no motion of the hand. If the hand goes down the scale, the connection tubing is not airtight. The air is probably getting out at one of the connections between the units of the tubing. Make certain that all connections are tight and then make another test. If the hand goes down scale again, the connection tubing is still not airtight. Take off one connection after another, and make the

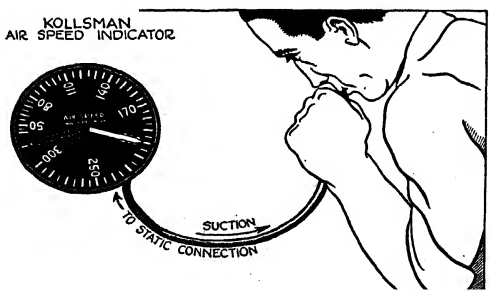


Fig. 39.—Testing tightness of case.

same test on every unit of tubing separately. The part of the tubing system that is causing the trouble may then be put right.

Make the same tests on the static connection tube to see that it is airtight (see Fig. 38).

[1] Using a small pump is better than blowing with the mouth. The Kollsman fuel quantity gage pump is very good for this purpose.

On some airplanes where the instrument board is on elastic supports, rubber tubes are used for joining the connection tubes to the instruments. Such rubber tubes are a frequent cause of trouble. Make certain they are soft and in good condition. Should they be hard, they are very probably not airtight. In addition, dust may be coming off the inside of the rubber tubes and getting into the instrument case. All rubber tubes about which there is any question are to be taken off and new ones used when the instrument is put back on the airplane.

To See If Instrument Case Is Airtight.—Put one of the rubber tubes on the static connection of the air speed indicator. Put the other end of this tube in the mouth and softly take in the breath, till the hand comes to 200 m.p.h. (see Fig. 39). If the range of the instrument is less than 200 m.p.h., take in the breath only till the hand comes to full scale. Then, shutting off the tube, keep watching the hand of the air speed indicator. If it goes down scale, see how quickly it is moving. If it is moving quicker than 5 m.p.h. in 1 min., the case is not tight enough.

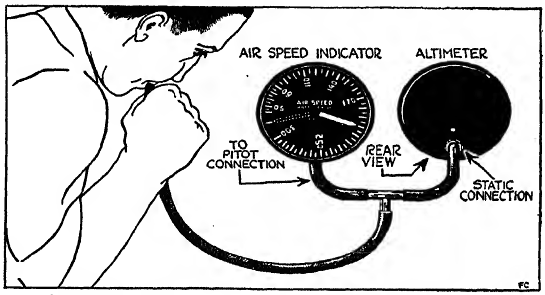


FIG. 40.—Checking altimeter case for leakage.

If the static tube has a connection to the altimeter, make a test of the altimeter case to see if it is airtight. Put one rubber tube on the connection of the altimeter case, another on the Pitot connection of the air speed indicator, and take the third rubber tube in the mouth, all three tubes being joined to the T connection. Keep watching the hand of the air speed indicator (Fig. 40). Air is to be pumped into the tube, while watching the hand, till the hand comes to 200 m.p.h. (or to full scale, if the range is less than 200 m.p.h.). If the hand goes down scale quicker than 5 m.p.h. in 10 sec., the altimeter case is not tight enough.

The connection of the Kollsman vertical speed indicator does not go to the inside of the instrument case. For this reason it is not necessary for the case of the vertical speed indicator to be tested. Even if the case is not right, it has no effect on the reading of the air speed indicator.

Apparatus for Tests in Workroom.—The Kollsman air speed indicator test stand is seen in Fig. 41. It has a liquid manometer and a "roller pump" on a base. The pump is very simple. It has two rollers between which a rubber tube is pulled when the parts are turned. This puts pressure in the tube. In addition there are, as in the apparatus for testing on the airplane, a T connection and three rubber tubes, one of which goes to the manometer. Of the others, one goes to the instrument to be tested and one is used with the pump.

Tests.—*Scale Error.*—The air speed indicator to be tested is placed in its normal upright position, and one of the rubber tubes is put on its Pitot connection. The other tube is placed in the pump. Turning the rollers puts the manometer and the air speed indicator under the same pressure. The pump is to be turned slowly, stopping at every one of the speed readings on the manometer given in Table 5, for the range of the instrument being tested. The reading of the air speed indicator, after the instrument is

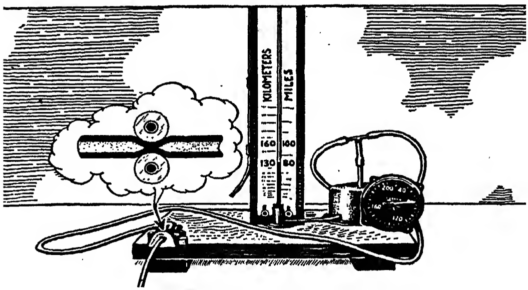


Fig. 41.—Kollsman air-speed test stand.

tapped lightly with a buzzer, is noted at every point. Limits of error are given in Table 5.

Friction Error.—At every test point marked with a star in the table, take two readings, the first without tapping the instrument; then, without changing the pressure, the instrument is to be tapped and the reading noted. The amount by which the second reading is different from the first is the friction error. Limits are given in the table for common ranges of instruments.

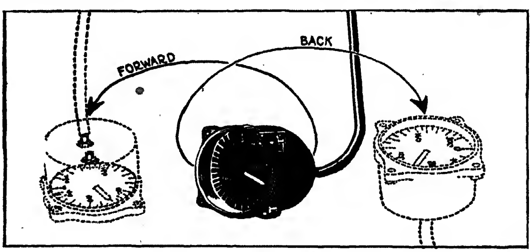


Fig. 42.—Turning instrument forward and back.

See, in addition, that the motion of the hand is smooth as the pressure goes up or down.

Position Error.—Put pressure on the instrument so its reading is that of one of the starred test points in Table 5. Without changing the pressure, the instrument is to be turned from its normal upright position through 90 deg., forward and back, and left and right (see Figs. 42 and 43). Take the reading of the air speed indicator after tapping lightly, when in these four different positions. These readings may be different from those in the

Table 5.—Common Ranges, Test Points, and Limits in Miles per Hour

Test Point	Limit	Test Point	Limit
60*	1.0	65*	1.5
100	1.5	130	2.0
125*	1.5	190*	3.0
150	2.5	250	4.0
175*	3.0	300*	4.0
200	3.0	350	4.0
Friction	2.5	Friction	3.5
60*	1.0	65*	2.5
110	1.5	160	2.5
150*	2.5	260*	4.0
190	3.0	350	4.0
220*	4.0	430*	4.0
250	4.0	500	4.0
Friction	3.0	Friction	3.5
65*	1.0		
120	2.0		
170*	2.5		
220	4.0		
260*	4.0		
300	4.0		
Friction	3.5		

* Test points marked with an asterisk are those at which friction and position tests are to be made. The limits of position error are the same as the limits of friction error given in this table.

normal upright position by the same amount given in the table as the limit of friction error. If the errors in any test are greater than those given, the instrument is in need of adjustment or repair. However, even if there are

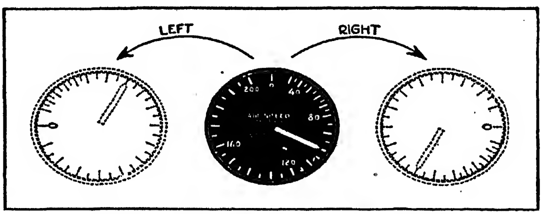


FIG. 43.—Swing instrument to right and left.

no errors outside the limits, the instrument has to be taken apart and cleaned after about every 1,000 hr. of use.

COMPASS

The compass gives the direction of the airplane in relation to magnetic[1] north. Any magnetic field makes the compass magnets take up positions parallel to its lines of force. If the only force acting on the compass is that of the magnetic field of the earth, the compass will give correct magnetic directions. However, the airplane generally has its separate magnetic field; the addition of this to that of the earth is the cause of compass errors.

Compass Compensation. *Apparatus.*—If the air field has a compass rose or turntable, the airplane may be placed on it and turned to any desired direction. If not, a surveyor's transit may be used to give directions.

Compensation.—Put all magnetic parts of the airplane (controls and tools) in their normal flight positions.

[1] The amount by which magnetic north varies from true north is the magnetic variation, or declination (see map, Fig. 52).

Table 6.—Speeds and Pressures

Speed, m.p.h.	Pressure, in. H_2O	Speed, m.p.h.	Pressure, in. H_2O
49.71		173.98	
50	1.23	*180*	16.17
55.92		180.20	
57.58	1.63	184.25	16.95
60	1.77	186.41	
62.14		*190*	18.04
68.35		192.62	
69.09	2.35	195.76	19.17
70	2.42	198.84	
74.56		*200*	20.03
80	3.16	205.05	
80.61	3.21	207.28	21.54
80.78		*210*	22.12
86.99		211.27	
90	4.00	217.48	
92.12	4.19	218.80	24.05
93.21		*220*	24.32
99.42		223.69	
100	4.94	229.91	
103.64	5.31	*230*	26.63
105.63		230.31	26.71
110	5.99	236.12	
111.85		*240*	29.05
115.16	6.56	241.83	29.51
118.06		242.33	
120	7.13	248.55	
124.27		*250*	31.59
126.67	7.95	253.34	32.47
130	8.38	254.76	
130.49		*260*	34.25
136.70		260.98	
138.19	9.48	264.86	35.58
140	9.73	267.19	
142.92		*270*	37.01
149.13		273.40	
149.70	11.14	276.37	38.84
150	11.18	279.62	
155.34		*280*	39.90
160	12.74	285.83	
161.22	12.94	287.89	42.27
161.56		*290*	42.91
167.77		292.04	
170	14.40	298.26	
172.73	14.87	299.40	45.85
		300	46.03

The airplane is first turned to the direction of magnetic north. Using a nonmagnetic screw driver, the N-S adjustment screw of the Kollsman polyplane compensator is to be turned till the reading of the compass is N.

The airplane is then turned to a west heading. Using the special screw driver, the E-W adjustment screw is to be turned till the reading of the compass is W.

The airplane is then turned to a south heading. The N-S adjustment screw is to be turned enough to take out *half* the error.

The airplane is then turned to an east heading. The E-W adjustment screw is to be turned enough to take out *half* the error.

For a complete compensation record the airplane is turned to headings 30 deg. apart and the compass reading noted at every heading, putting the reading down on a compensation card like this:

For	N	330	300	W	240	210
Steer	2	333	300	269	240	209
For	S	150	120	E	60	30
Steer	178	147	119	91	61	32

No *tests of the compass* should be made *on the airplane.*

Tests in Workroom.—For testing compasses it is best to have a place where the only magnetic field is that of the earth. If other magnetic fields are present, it is necessary to see that they are fixed in direction. To be certain that a place will be free of trouble, put a compass on test there and make notes of its readings over a long time. If there are no changes in the readings, the place may safely be used for testing compasses.

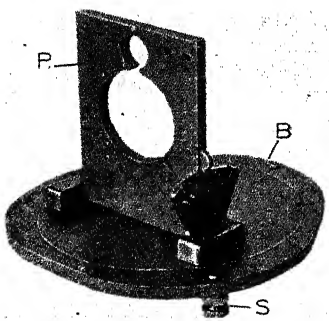


FIG. 44.—Turntable for testing compasses.

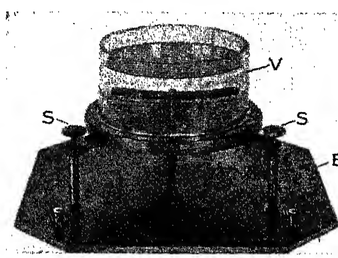


FIG. 45.—Compass-card balancing stand.

Apparatus Used.—A turntable for testing compasses is seen in Fig. 44. It has a base B, three leveling screws S, and a plate P, to which a compass may be fixed. The plate may be sloped to the front or back and locked in that position.

A card balancing stand is seen in Fig. 45. It has a base B and a glass vessel V, with three screws S for leveling. In the vessel is a jeweled pivot post on which compass magnetic units may be placed for balancing.

If compass magnets are to be remagnetized, a magnetizing apparatus is needed in addition. This is seen in Fig. 46. It has a base B, two windings W, a switch S, and a connection C for 120 volts d.c. Special pole pieces P are used for different designs of compass magnets.

To Put Compensator in Zero Position.—Put the compass on the turntable. Put the turntable in the north position. The N-S adjustment screw is to be turned till the compass reading is N, when tapped[1] with the finger or with a pencil.

[1] It is not possible to make use of an electric buzzer with a compass, as the electric field of the earth will be put out of place by the electric field of the buzzer.

Put the turntable in the west position. The E-W adjustment screw is to be turned till the compass reading is W.

Put the turntable in the south position. If the compass reading is not S, the N-S adjustment screw is to be turned to take out *half* the error. Put the turntable in the east position. If the compass reading is not E, the E-W adjustment screw is to be turned to take out *half* the error.

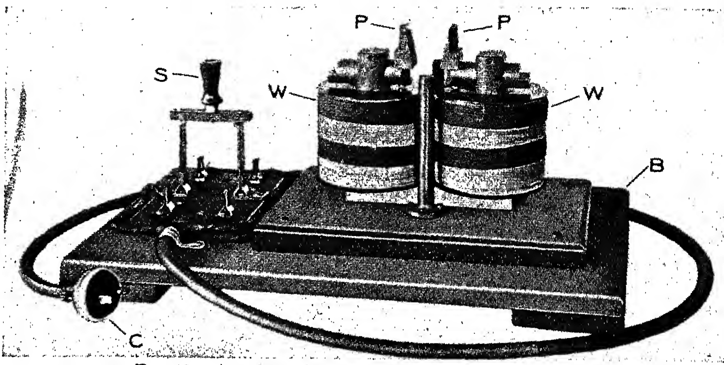


FIG. 46.—Apparatus for remagnetizing compass magnets.

Scale Error.—With the compass in place, turn the turntable to every 30-deg. position and note the reading of the compass, after tapping, in every position. The amount by which the reading may be different from the true direction is given in Table 7 as scale error.

Friction.—Using a small magnet, pull the compass card 5 deg. out of its normal position. Take away the magnet. If the card goes back to the same position, the compass has no friction. If the card does not go back

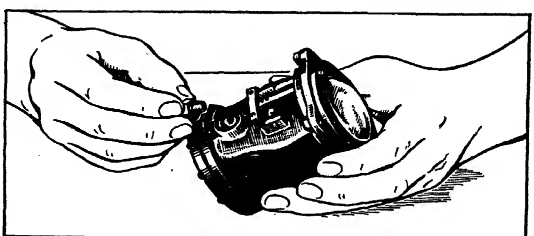


FIG. 47.—Taking filler screw out of compass.

to the same point, make note of the number of degrees it is off. This is a measure of the friction. The limit is given in Table 7.

Period.—Using a magnet, the compass card is to be pulled to a position 30 deg. away from its normal position. Take the magnet away quickly, and make note of the time taken by the card to go past a position 5 deg. short of its normal position. Limits for this time are given in Table 7.

Compass, Type 132B. *To Take Apart.*—Take out the filler screw, Fig. 47. If the compass is turned over, the liquid will come out. To let the liquid out more quickly, put a small tube in the filler hole to let air into the case on top of the liquid.

Take out the front ring screws and take off the front ring. Put a soft rubber washer on the compass glass and put on this washer a glass puller. This glass puller is a small instrument case which has a connection to a vacuum line. The puller is to be pushed hard on the washer, and the con-

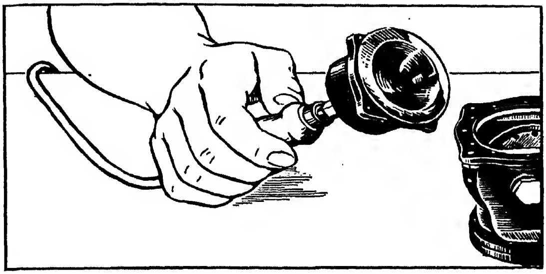


Fig. 48.—Vacuum cup for removing glass.

nection to the vacuum line is to be opened. The glass will be pulled off as in Fig. 48.

Using a small screw driver, the lubber's line is forced out. Take out the magnet unit, using a special wrench, as in Fig. 49. The unit may be lifted out with the fingers.

Take out the screws from the back plate, which will come loose if it is hammered gently around the edge. Take off the back plate and spring.

Take off the diaphragm and gaskets, pulling them free with care.

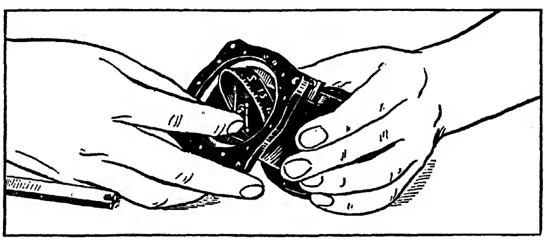


Fig. 49.—Removing the magnetic unit.

To take the magnet unit apart, the small snap ring is first to be pushed down. Then the jewel post is to be pulled out.

The parts of the compass are seen in Fig. 50. They are: case; front ring; screws; outer gasket; glass; inner gasket; magnet unit; lubber's line; jewel post; back plate; spring; back plate screws; diaphragm; and gaskets.

Remagnetizing the Magnetic Unit.—If the test for the period gave a time longer than the limit in Table 7, the magnets are not strong enough. Put the magnetic unit on the apparatus (Fig. 46) with the magnets placed so that

the N on the card is over the letter N on the apparatus. The switch is to be closed and opened four or five times.

Balancing the Magnetic Unit.—After making the magnets stronger, the magnetic unit is to be balanced in liquid. Put it on the pivot post of the balance stand (Fig. 45). If the card is not in balance within the limit given in Table 7, put a small amount of solder on the high ends of the magnets. Do this with a soldering iron which is no hotter than necessary. Be certain

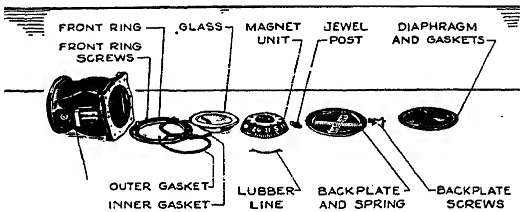


Fig. 50.—Parts of Kollsman type 132B compass.

that all flux is washed off after the solder is put on. The soldered ends should be painted black.

Cleaning.—Wash all parts in carbon tetrachloride. It is especially important to see that the bowl is free of dust and small bits of metal. The glass may be washed with soap and water and dried with a soft clean cloth.

Move a sharp metal point all around on the face of the jewel to see that there are no cracks. The pivot should be looked over carefully to see that its point is sharp.

Putting Together.—The process of putting the compass together is the opposite of that of taking it apart. After putting it together, put clean liquid in it.

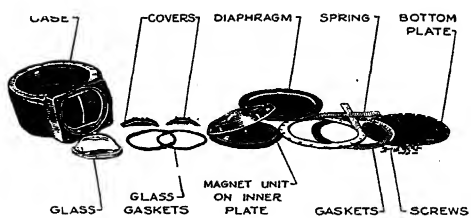


Fig. 51.—Parts of type 65BL compass.

Compass, Type 65BL. *To Take Apart.*—Take out two screws and take off the upper cover. Take out two screws and take off the lower cover. Take out the screws around the front ring and take off the front ring.

Take off the glass, using the glass puller as in the directions for the type 132B compass. Take out the screws and take off the bottom cover.

Take out the spring, diaphragm, and gaskets. Take out the screws and take off the inner plate with the magnet unit.

The parts of this compass are seen in Fig. 51. They are: case; glass; glass gaskets; upper cover; lower cover; magnet unit on inner plate; diaphragm; gaskets; spring; bottom plate; and screws.

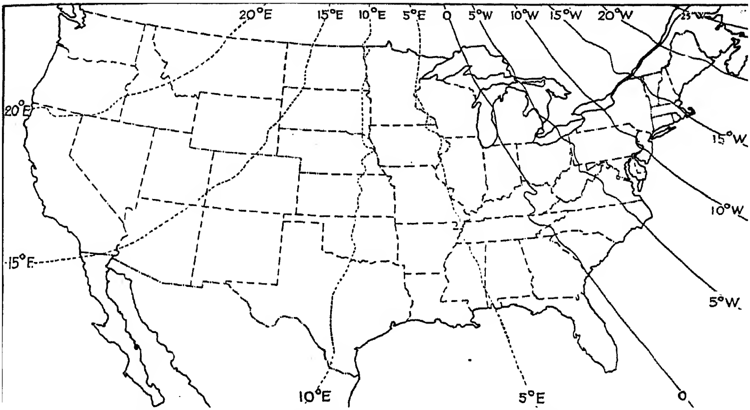


FIG. 52.—Map showing magnetic lines in the United States.

The magnet unit is taken apart and is remagnetized in the same way as the other compass.

Table 7.—Allowable Limits

Test	Type 132B	Type 65BL
Scale error, deg.	2	½
Friction, deg.	1	1
Period—time from 30 to 5 deg.:		
Not more than	3 sec.	5 sec.
Not less than	2 sec.	3.5 sec.
Error with compensator, deg.	2	2
Balance—level within, deg.	2	2

PIONEER AUTOSYN

Autosyn is the name given a system of remote indicating instruments; it meets one of the basic requirements of multimotor airplane design by making possible accurate remote indication of the functions of the aircraft and its engines through efficient electric transmission. A combination of simple transmitting and indicating elements, which may be widely separated, comprise the basic units of the system. It is made by the Pioneer Instrument Co.

How It Works.—Autosyn applies the principle of self-synchronous motor operation. The prime function of self-synchronous motors is the duplication of motion of one motor in another. These two motors, which may be remotely separated, operate in exact synchronism, the rotor of one motor following the least motion of the rotor of the other. Simple electrical wiring between these two units eliminates all mechanical connections and tubing.

This of course requires alternating current. The Autosyn system can be designed to operate under any combination in a wide range of voltage and frequency. If alternating current is not available or is not a part of the aircraft's power supply, a separate generator may be included as part of the accessory equipment.

In aircraft Autosyn the motors are used only to duplicate the extent or position of an instrument function at some remote point. Although rarely called upon to operate in continuous rotation, the units are known as "motors" for the purpose of explanation. Autosyn within itself functions primarily as a phase-indicating device capable of continuous operation for hundreds of hours in service without attention.

The Autosyn system consists essentially of a transmitting unit located near the source of measurement, and a receiving or indicating unit mounted on the instrument board. Both units contain, as an integral part, a small Autosyn "motor." The transmitting "motor" is attached directly to the sensitive instrument element, the whole assembly being located conveniently near the source of measurement. Connected to the indicating "motor" on the instrument board a pointer establishes a position in synchronism with the transmitting unit.

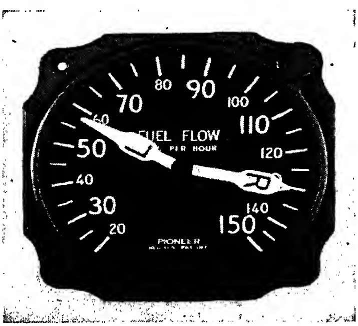


FIG. 53.—Autosyn fuel-flow indicator.

The sensitive element of the transmitter is connected mechanically to the source of measurement. The element, for example, may be an oil pressure Bourdon tube or a fuel pressure diaphragm. The sensitive element rotates the rotor of the transmitting "motor" in the same manner as it would a pointer on a dial.

Simple wiring carries current to the indicator on the instrument board to correspond to the position of the transmitting rotor. The indicating motor operates directly a pointer on a dial which is calibrated with a scale corresponding to the function measured. Any movement of the sensitive element in the transmitter is immediately registered by a corresponding movement of a pointer on the indicating dial.

The instrument board indicators consist simply of Autosyn "motors" with pointers attached to their rotor shafts. One development is the dual indication of two functions on a single dial. This is done with the tandem indicator which contains two motors, the shaft of the rear motor extending through the hollow shaft of the front motor. By this means, the indications of right- and left-hand engines of a bimotor, or each pair of outboard engines of a four-motor ship, are given by two concentric pointers on a single dial. Similarly the fuel quantity of two tanks may be simultaneously indicated on one dial. The pointers are designed readily to identify the source of the measurement.

A further development is the use of a selector switch in conjunction with multiple-scale indicator, so that a single indicator might be used for several functions, such as oil, fuel and manifold pressure, and oil temperature. Several scales, properly identified, are incorporated on a standard size dial. A two-pointer dual or tandem indicator, together with a four-scale dial and

selector switch, makes possible a combination of *eight instruments* in one. The principal advantage of this arrangement lies with the greater ease of reading by the pilot and the conservation of instrument board space. Where it is necessary to have continuous indication of all instrument functions, such as in the flight engineer's compartment, the indications can be duplicated by individual indicators.

Single-phase alternating current is used for supplying the energy to the Autosyn system. The standard current is either 32 volts-60 cycle, or 110 volts-800 cycle. There are several possible sources for this a.c. supply.

Instrument Applications.—Autosyn transmission applied to the airplane may be adapted to the remote electrical indications of almost any desired instrument function.

Engine Gages.—For engine conditions of pressure and temperature, standard instrument elements such as Bourdon tubes and diaphragms are mounted as part of the transmitting Autosyns. For multimotor airplanes, dual indicators in conjunction with selector switches and warning lights are desirable. These give the pilot all the engine information necessary, and save confusion and instrument board space.

Tachometers.—A conventional type mechanical tachometer element is connected directly to the transmitting Autosyn. The value of a short flexible cable is apparent in this case.

Fuel Flow Indicators.—The transmitting element, located in the fuel supply line to each engine, operates a quantity per unit time indicator. Autosyn has made possible accurate fuel flow indication, as in Fig. 53.

Fuel Quantity Indicators.—Standard fuel level elements of an improved design, principally of the float type, are incorporated with Autosyn transmission.

Position Indicators.—Autosyn transmission is particularly adaptable to remote indication of position of landing wheels, tail wheel, flaps, control surfaces, and doors.

Radio.—Where radio equipment is installed in the rear of a ship, tuning can be accomplished by electric motor drive controlled from the cockpit. Autosyns can be used to transmit the position of the condenser being tuned. Also, Autosyn can be used accurately to indicate radio loop bearing indications on a dial on the instrument board.

Advantages of Autosyn System.—1. Autosyn combines accuracy and reliability, together with simplicity and ruggedness.

2. It eliminates long tubing and drive shafts which are replaced by electric multiwire conductors.

3. It eliminates errors in oil pressure indication due to oil congealing in the capillary under low temperature conditions.

4. It eliminates fuel and oil lines from the pilot's compartment, reducing the fire hazard and engine and failure possibilities.

5. It conserves instrument board space on the panel by using dual and multiple scale indication which results in greater ease of reading by the pilot.

6. Service requirements are reduced to a minimum due to the simplicity and accessibility of the equipment and the elimination of long tubing, which is the principal source of trouble.

7. Sufficient spare conductors can be included in each cable to allow quick substitution of any broken conductor or addition of new instruments.

8. The removal of wings is facilitated by conveniently locating a terminal box or multiple plug near the junction.

9. The only connection between the transmitters and indicators is the small electrical conduit.

10. Both transmitting and indicating motor elements are very nearly identical, the case being the principal difference. Instrument board indicators are fully interchangeable by change of dial.

11. Alternating current, which is a required part of the system, can be used for ultraviolet light instrument panel illumination. Although the radium paint is extremely sensitive to ultraviolet, the visible "white light" cockpit illumination is kept at a minimum. This results in increased pilot-

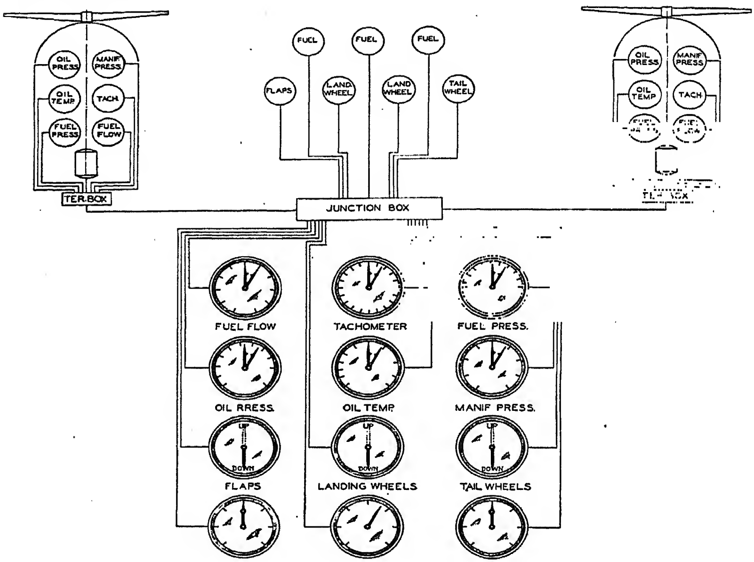


FIG. 54.—Autosyn wiring connections for a two-engine plane.

ing efficiency and, in military aviation operation, adds a special feature of safety.

12. Autosyn transmission may be adapted to almost any conceivable instrument application.

Figure 54 shows the instruments and wiring on a two-engine plane; Fig. 55 a different layout for a four-engine plane. There are modifications to suit any requirements.

It is recommended that the transmitting element be located as close to the source of measurement as convenient so as to reduce as much as possible the length and weight of such mechanical connections as tachometer shafts and tubing. In each engine nacelle, several transmitters may be grouped together in a common junction box where they are easily accessible without causing interference. A shockproof mount can be used, but it is not

absolutely necessary, for Autosyn instruments are in themselves inherently very rugged.

Five similar terminal connections are provided on the rear of both the transmitting and indicating units. Three designated "1," "2," and "3" come from the stator and should be connected to the corresponding terminals of the other unit. Terminals marked "A" and "G" are from the rotor and are the power wires carrying the alternating current. The "A" and "G" terminals of all the transmitting and indicating motors in the system are connected in parallel to the a.c. supply. A recommended method is the use of a single wire between all "A" terminals, with the "G" terminals grounded to the structure.

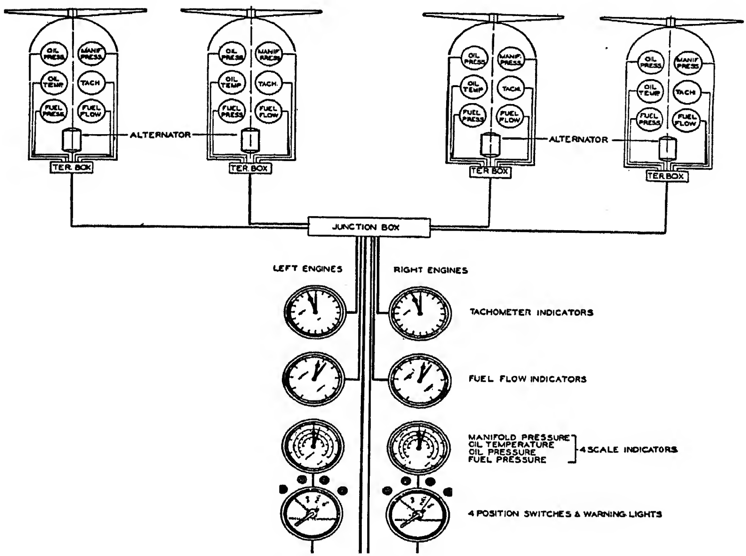


Fig. 55.—Autosyn wiring diagram for a four-engine plane.

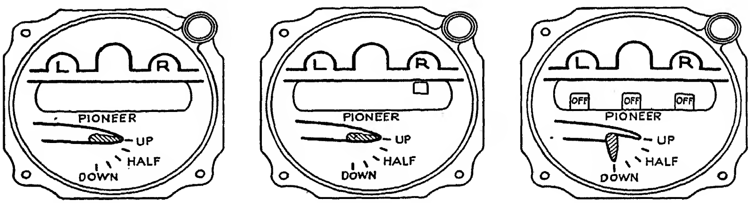
Either individual wires or multiconductor cables can be used. Where the system comprises several instruments, a cable is best. Wires of the smallest practical size, from a mechanical standpoint, can be used. Assuming engine installations of fuel, oil and manifold pressure, oil temperature, fuel flow, and tachometer Autosyns in a bimotor, 18 conductors would be needed between the cockpit and each nacelle. The two power terminals of each transmitter and indicator are connected directly to the a.c. power supply of the airplane. A recommended installation would be a cable of 22 conductors which would have an over-all diameter of about ⅜ in. The spare conductors could take care of a possible added Autosyn instrument and could be used where replacement in service is necessary. Such a cable, permanently installed, should last the life of the ship without attention or replacement.

D.C. Autosyn Position Indicator

An interesting development in connection with the modern retractable landing gears is the Pioneer wheel and flap position indicator, which provides the pilot with a definite knowledge of the position of each one of the retractable wheels (or pontoons), the action of all locks used to maintain these retractable components in position, and the position of the flaps.

All these functions are extremely important for the safe operation of any airplane. With this instrument, the pilot can see at a glance if the flaps and retractable landing gear are firmly locked in place. Special dial arrangements are available for ships that retract only two wheels, and for ships that do not have mechanical locks for retaining the wheels in the up position.

As a safety factor, a definite power on-and-off indicator is provided. This permits the pilot to depend on the indications of this instrument at all times and absolutely prevents his reading the instrument at a time when the power is turned off. The instrument operates from a d.c. power supply and is basically a d.c. Autosyn. The transmitter and indicator are synchronous



All wheels up and locked Flaps up — Right wheel unlocked — Power off

FIG. 56.—Landing gear Autosyn with plane in flight.

and the indications are independent of line voltage or length of leads between transmitter and indicator. The wheel lock indicator uses the standard wheel lock switches.

In the design of this system, every possible safety consideration has been included. The dial layout is designed for the utmost simplicity, and yet gives the pilot all the information he needs about his landing gear and flaps at a glance.

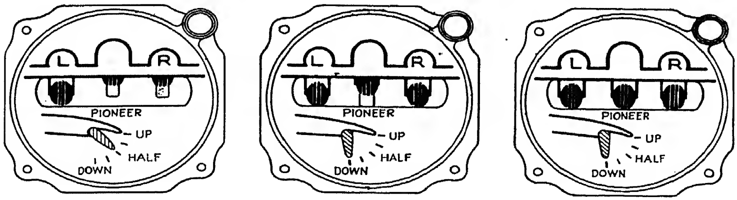
On the dial of this instrument all the components of the airplane that it covers are represented by small flags appropriately painted. In the upper part of the dial is a simulation of the outline of a twin-engined airplane. Under the center of the fuselage and under each nacelle, small flags move up and down. Each of these flags is luminously painted to represent a wheel.

In the lower half of the dial is sketched the outline of an airplane wing. In its appropriate position is mounted a small luminously painted pointer, shaped to represent a flap.

When the instrument is operating, the three small "wheels" and the "flap" move up and down exactly in step with their corresponding elements of the airplane.

Thus, in the left-hand figure (Fig. 56) the wheels are fully retracted into the ship and the flaps are closed. In the center figure, the wheels are fully retracted but the right-hand main wheel is not locked "up."

If, for any reason, the power supply to the system should be cut off, the three "wheels" would drop out of sight, leaving only three little tabs reading "off." The illustrations (Figs. 56 and 57) explain themselves.



Left wheel down and locked
Right and tail wheels part way down
Flaps part way down

Danger
Tail wheel not locked

All wheels down and locked
Flaps full down

Fig. 57.—Landing gear Autosyn with plane about to land.

For airplanes not equipped with a retractable tail or nose wheel, the indicator is available with only two wheel-indicating flags. For installations that do not use wheel locks, transmitters are available with built-in step

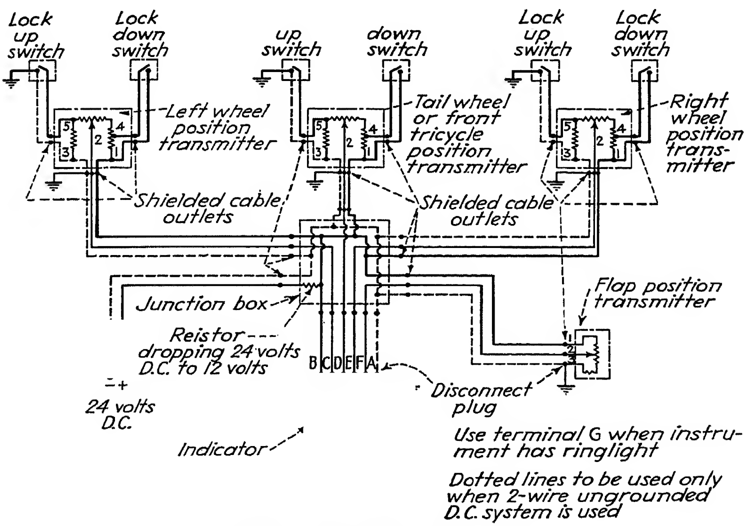


Fig. 58.—Wiring diagram of Autosyn.

resistors for accelerated end travel. When these are used, the red flag is visible until the wheel is almost up (or down). The last small motion of the wheel will cause the disappearance of the warning indicator.

There are two types of transmitter rotation available with this installation. The "−1" rotation requires a clockwise movement of the transmitter linkage fitting for an ascending or wheel up indication. The "−2" rotation requires a counterclockwise movement of the transmitter linkage fitting for an ascending indication. The type of rotation desired should be specified on ordering.

To assure adequate readability for night flying, the indicator is available with the Pioneer ringlight. All of the position indicators are supplied with standard and disconnect plugs.

Installation.—A wiring diagram is shown in Fig. 58 for a grounded d.c. system. The necessary connections for an ungrounded system are shown in dotted lines. The numbers shown on the wiring diagram correspond to the numbers on the terminal blocks and disconnect plug of the system. Installation dimensions of the instrument are shown in Fig. 59.

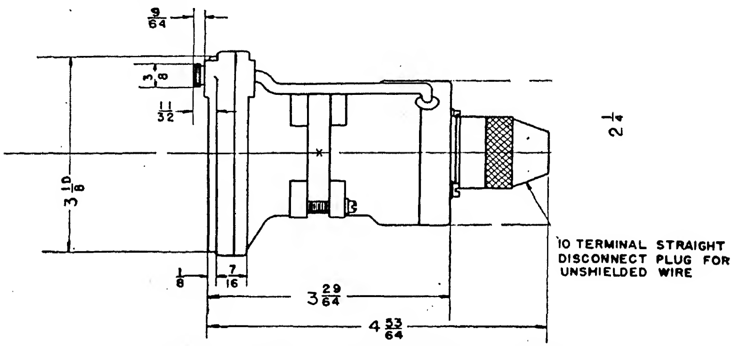


FIG. 59.—Installation dimensions of Autosyn indicator.

The power supply is direct current of either 12 or 24 volts (must be specified when ordering). The operation of this system is not dependent on a constant voltage supply and the usual ship supply variations will not affect it. The entire system draws about 1 amp. (at 12 volts).

The transmitters are connected to the flaps and retracting gear with a simple linkage that permits some range and zero adjustment. After installation the instrument is adjusted so that the individual "wheels" move in the proper positions as indicated on the installation instructions shipped with each instrument.

For maximum service life, it is recommended that the indicator be mounted on a panel suitably damped from vibration. The instrument should not be subjected to vibrations of more than 0.008 in. total amplitude.

Ringlight leads are included in the disconnect plug. Suitable resistors are built into the indicator to maintain the ringlight current to 0.2 amp., when 12 volts are applied to the system.

It will be noted that this Autosyn uses direct current.

PIONEER TURN AND BANK INDICATOR

The turn and bank indicator (Fig. 60) combines in one instrument two functions essential to the accurate control of aircraft, particularly when

operating under conditions of reduced visibility. It provides, with reference to the straight flight path, indication of the direction and the rate in degrees per minute of a turn. The sensitive element of the turn indicator is a gyroscope operated at approximately 10,000 r.p.m. by an air stream impinging on its blades through a jet at the top rear of the instrument case. The source of the air stream is a pressure differential caused by application of suction equivalent to 2 in. Hg to the instrument case, below the gyro wheel. The gyro rotates, on ball bearings, about the lateral axis in a frame which is pivoted on ball-bearing supports, about the longitudinal axis. Deviation of the aircraft from the straight flight path causes the gyroscope to precess to right or left about the longitudinal axis depending on the direction of turn. The precession force is approximately proportional to the angular rate of turn. The precession motion is opposed by an adjustable centralizing spring linked to the gyroscope frame and is transmitted by levers to the pointer. Necessary damping of the precession motion is done by a simple piston-and-cylinder device with an adjustable valve, the piston being linked to the gyroscope frame. A service feature of the turn indicator is the fact that calibration and damping adjustments are made externally by two screw adjustments, one on each side of the case. The banking is shown by a metal ball sealed in a curved glass tube which is filled with a damping liquid. It provides a positive indication of the lateral attitude of the aircraft. Combined with the turn indicator, it may be used to control the ship accurately during maneuvers. The bank indicator does not require service attention unless damaged, when it must be replaced.

Details of its construction are shown in Fig. 61.

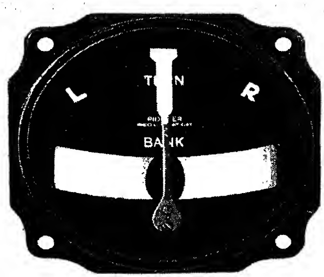


FIG. 60.—Pioneer turn and bank indicator.

The suction supply connects at the bottom rear of the instrument case. It is recommended that suction be obtained from an engine-driven vacuum pump or from the intake manifold of the engine. In either case a relief valve, or suction regulator, must be installed in the line running to the instrument, to ensure an unvarying suction supply at the correct value of 2 in. Hg.

Should a venturi tube be employed as the suction supply, particular care must be used in locating the venturi to ensure that the vacuum supply will be of correct value under normal cruising conditions. The venturi should be mounted in the unobstructed flow of propeller slip stream, as close to the instrument board as is feasible. It should also be located adjacent to the exhaust manifold, if possible, to prevent the freezing of moisture in the tube.

The turn and bank indicator is designed to indicate correctly at a suction of 2 in. Hg. It is important that each installation be checked to ensure the maintenance of the suction supply at that figure. For this purpose, a suction gage may be connected to the extra outlet in the case of the indicator, which is otherwise sealed with a pipe plug.

Disassembly.—The eight bezel screws are withdrawn from the front of the instrument, permitting removal of the bezel ring and cover glass assembly.

Two hand screws are removed and the hand lifted from the handstaff. During this operation the hand must be held in zero position, imposing no

strain on the handstaff or fork. A suitable handstaff holding wrench should be used.

The dial may be lifted out after the removal of the three dial screws.

The rubber packing is withdrawn and the two clinometer plate screws removed. The bank indicator assembly may be lifted out, and may be further disassembled, if necessary, by removing the two wires.

The handstaff assembly may be lifted out after the removal of the two bearing plate screws. The handstaff must not be turned during this opera-

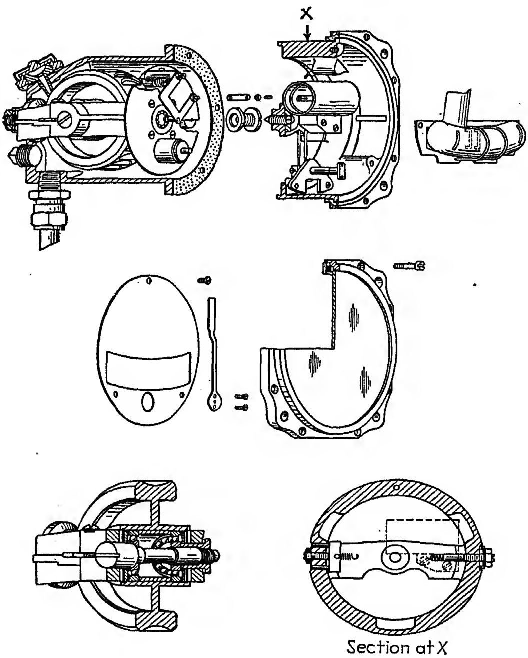


FIG. 61.—Construction details of Pioneer turn and bank indicator.

tion and the assembly should be handled with care. If necessary, further disassembly procedure is as follows:

The fork hub screw is removed and the fork hub assembly withdrawn. The handstaff is lifted out and the two handstaff bearing screws removed, permitting withdrawal of the handstaff bearing.

To remove the matched cylinder and piston assembly, withdraw the link pin and link pin washer from the piston link. Removal of the two cylinder support screws permits the assembly to be lifted out and the piston may be withdrawn from the cylinder. Note that there are a valve pin and valve spring in the base of the cylinder. The tapered end of the valve pin should

be outermost. Care must be used in handling the piston and cylinder assembly to avoid marring the fit or surface finish in any way.

Using tweezers, the centralizing spring may be unhooked from the spring adjustment stud and removed.

Removal of the Gyro Assembly.—The connection fittings and the air jet should be unscrewed from the instrument case.

Turning the instrument face down, remove six screws from the case front ring.

The lock nut and gyro frame bearing pin at the back of the case are loosened sufficiently to allow the gyro assembly to drop clear.

The case and case front ring may next be separated and the gyro assembly removed. Avoid catching the dashpot lever, attached to the gyro front balance plate, on the cross member of the case front ring. The position of the dashpot lever is important. It should not be distorted or damaged in any way.

Disassembly of the Gyro Assembly.—Four screws are removed from the gyro balance plate and the balance plate assembly separated from the gyro frame.

The two clamp screws and their lock washers are unscrewed from the gyro frame at the ends of the gyro wheel shaft.

The nut of the gyro wheel shaft is held with a wrench while the shaft is loosened at the opposite end with a screw driver. The shaft is withdrawn and the gyro wheel may be removed from the frame.

The ball bearings and their covers are removed from the inside of the frame.

With a pair of tweezers, the retainer ring, corrugated washer, bearing plate, and paper gasket are removed from one side of the gyro wheel hub. Similarly, the retainer ring, bearing plate, and paper gasket are removed from the opposite side of the hub. The two ball bearings and the hub spacer may then be removed from the gyro wheel.

Assembly.—The assembly procedure is essentially the opposite of disassembly. However, the following notes are added as an aid in assuring proper functioning of the completed instrument:

The absolute cleanliness of all working parts is of extreme importance, particularly the ball bearings, piston and cylinder assembly, frame bearing pins, and handstaff assembly. These parts may be washed in clean benzene or a light oil heated to approximately 212°F., and dried promptly and thoroughly. Bearings or other parts that are corroded or pitted must be replaced. The surfaces of these parts must be clean and have a high polish.

Perfect balance is the key to proper functioning of the gyroscope. The gyro wheel alone, without ball bearings, is first checked for balance on a special fixture. When balanced, the wheel will not stop consecutively at the same point, after spinning. Should a "heavy" spot be found, sufficient material may be drilled away at that point on each side of the wheel rim, using a 1/8-in. drill.

The hub spacer and the ball bearings may be assembled into the gyro wheel, the ball bearings being a light press fit in the wheel hub.

The paper gasket, bearing plate, and retainer ring are assembled into one side of the wheel hub. The ball bearings and hub spacer should then be pressed over against those parts, from the other side of the wheel hub.

The paper gasket, bearing plate, corrugated washer, and retainer ring may next be assembled into the other side of the hub.

The bearing covers and ball bearings are pressed into position in each end of the gyro frame.

The gyro wheel is placed in position in the gyro frame, with the corrugated washer of the wheel on the counterbored side of the frame. The wheel shaft is then inserted from the side of the frame not counterbored. The gyro wheel should first be centered in the frame by eye and the adjusting nut tightened on the wheel shaft, permitting the wheel approximately 0.0004 in. end play. The punch mark on the adjusting nut must be on the center line of the slot in the frame.

All ball bearings should be lubricated only with about two drops of special gyro oil.

To check the centering of the gyro wheel in the frame, the gyro assembly may be mounted between centers of a lathe, on its own frame bearings. The wheel shaft is shifted until the wheel appears centered in the frame and the clamp screws in the frame tightened onto the ends of the wheel shaft. With the wheel spinning rapidly, the frame is revolved slowly on its bearings. Unbalance may be corrected by loosening the shaft clamp screws, shifting the position of the wheel, and retightening the clamp screws. This should be repeated until perfect balance is attained.

The front balance plate is secured to the gyro frame by its four screws. The complete gyro assembly must be again checked for balance using the lathe centers as previously noted, and allowing approximately 0.002 in. end play between frame and centers. A suitable small weight should be temporarily attached to the gyro balance plate, as a substitute for the weight of the piston link and piston. Unbalance is corrected by drilling material from the counterweight on the balance plate, or by shifting the position of the second, adjustable counterweight in its slot.

Note: During all balancing operations, whenever it is necessary to drill away material, it is vitally important to prevent particles from falling into the ball bearings. A suitable gyro cover may be made for this purpose, or a Pioneer bearing protection cover may be employed.

The case connections fittings and the air jet are screwed into the case, using a suitable sealing compound on the threads. In assembling the gyro assembly into the case and case front ring, the rear gyro frame bearing pin, with its lock nut, is set loosely in the case. The front frame bearing pin, in the case front ring, should be so adjusted that when the gyro assembly is in position on this pin, the dashpot lever on the gyro balance plate will be located centrally with respect to the damping cylinder. With the case front ring face side down, and the gyro assembly located on the front frame bearing pin, the case is brought down over the gyro assembly and the rear bearing pin located in its frame bearing. The case is then secured to the case front ring with six screws. During this operation, the rear frame bearing pin must be backed off sufficiently to prevent its "binding" in the frame bearing.

The rear frame bearing pin should be adjusted to permit the gyro assembly approximately 0.001 in. end play. The locking nut is then secured firmly in place.

The remainder of the instrument assembly requires little special comment. In mounting the matched piston and cylinder assembly, the piston link must not "bind" in any way, and should be permitted a small amount of side play. It is important that no oil be used between piston and cylinder. A drop of very light instrument oil may be used on the piston wrist pin. The tapered end of the cylinder valve pin must be outermost.

A drop of light bearing oil may be used on the handstaff bearing. Play between the hub fork and handstaff should be the minimum that will prevent sticking.

The bank indicator wires must be tight and its parts perfectly clean. After assembly into the instrument, it should be checked with the aid of a level. The ball should be centered and between the two wires when the instrument is level.

Before the cover glass and bezel are assembled, the calibration of the instrument may be checked, using pressure rather than suction. This is accomplished by connecting a pressure line (free from dirt or moisture) to the air jet at the back of the case and applying pressure equivalent to 2 in. Hg. *With the cover glass assembled, the instrument must be operated only on suction.*

Calibration.—A suitable turn indicator test stand (Pioneer type E-410) is required for calibration of the turn and bank indicator. The suction supply must be maintained at 2 in. Hg., and the instrument is subjected to known rates of turn, in degrees per minute.

With the instrument in any position, the gyro not spinning, the pointer should indicate zero within 0.008 in.

With the instrument in normal position, the gyro operating at a suction of 2 in. Hg, the pointer should read zero within 0.008 in. Pointer oscillation should not exceed $\pm 1/64$ in.

With the instrument in normal position, not being subjected to vibration, a suction of 0.4 in. should cause the gyro to rotate.

Failure to pass the above tests indicates worn or rusty bearings, dirt in the working parts, loosely fitted parts, or an unbalanced gyro assembly.

With the instrument in normal position, operating on a suction equivalent to 2 in. Hg, it should be adjusted to read as follows:

Rate of turn, deg. per min.	Pointer deflection from zero, in.	Tolerance, in.
36	$1/16$	$-1/64$
180	$5/16$	$1/64$
360	$1/2$	$1/16$
1080	1	$1/8$

Calibration adjustments are made by means of the screw marked "S" on the left side of the case. Turning this screw *in* decreases the tension on the centralizing spring and increases pointer deflection from zero. Upon completion of adjustments, the locking nut secures the screw firmly in place.

With the instrument in normal position, under suction equivalent to 2 in. Hg, it should be rotated about the vertical axis at a rate sufficient to cause full-scale deflection of the pointer. When the turning motion is suddenly stopped, the pointer should return to zero without crossing the zero mark more than twice. It should not exceed $1/4$ in. past the zero mark on its first crossing, nor $3/64$ in. on its second crossing. Damping of this motion is secured by adjustment of the screw marked "D" on the right side of the instrument case. This screw controls the valve of the cylinder and piston device. Turning the screw *in* decreases the damping action and vice versa. This adjustment is also secured by means of a locking nut.

Service Checks.—After each 400-hr. period of operation the plug under the word "Oil" on the instrument case should be removed. About four

drops of gyro oil may then be applied to the wick. The gyro should not be operating during lubrication.

The air jet cover, located at the top rear of the instrument case, should be cleaned at each inspection period.

PIONEER DRIFT INDICATOR

As is well known, a plane may be headed in one direction yet follow a course in another direction. The difference between heading and course is the drift angle. In order to "make good" the desired course, the pilot (or navigator) must know the drift angle so that he may calculate the heading and steer his plane accordingly. The only practical way of ascertaining the drift is by observation of the ground, and a drift indicator is used for this purpose.

In the top of the instrument is mounted a ground glass $3\frac{3}{8}$ in. in diameter. A lens is inserted in the bottom of the funnel-shaped case. As the plane moves in the air, an image of the ground below is thrown upon the groundglass screen and objects on the ground appear to travel across the screen in the direction of the movement of the airplane. The screen itself is rotatable and is provided with parallel sight wires and an angular scale graduated in degrees from 0 to 50 on both sides of zero (Fig. 62).

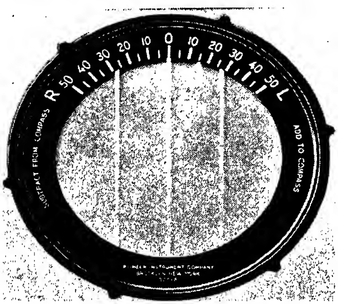


FIG. 62.—Pioneer drift indicator.

To observe the drift, it is necessary only to rotate the screen either to the left or the right until objects on the ground appear to travel in a line along the screen parallel to the sight wires. The angle of drift is then read directly from the scale. To correct the compass course, simply add or subtract the number of degrees of drift.

In night flying, lighted objects, such as street lights or electric signs, show up on the screen with remarkable clearness. This makes it as easy to take a drift reading at night as in the daytime, provided of course the ship is passing over lighted objects of sufficient brilliancy.

Installation.—To install, it is necessary to cut a hole in the floor of the plane of the proper size and fasten the drift indicator in place. It is very important to make sure that it is mounted so that the sight wires will be parallel to the fore-and-aft axis of the ship when the screen is set to a zero reading. Details are seen in Fig. 63.

To check the fore-and-aft position, a cord should be stretched on the ground under the instrument, exactly parallel to the fore-and-aft line of the ship. Holding the top ring of the instrument on zero, rotate it so that the cord will be sighted exactly parallel to the sight wires. Any error in the fore-and-aft alignment will cause a similar error in all readings. If the airplane has the fuselage cover carried below the floor on fairing strips, a hole large enough for the lens should be cut in the covering. In case the latter is further beneath the floor than the length of the instrument, a cone which includes the full angle of vision of the instrument should be made extending from the bottom of the instrument to the outside surface of the airplane. The diameter of this cone at the bottom of the airplane should be equal to

the distance from the lowest point of the instrument to the bottom of the airplane.

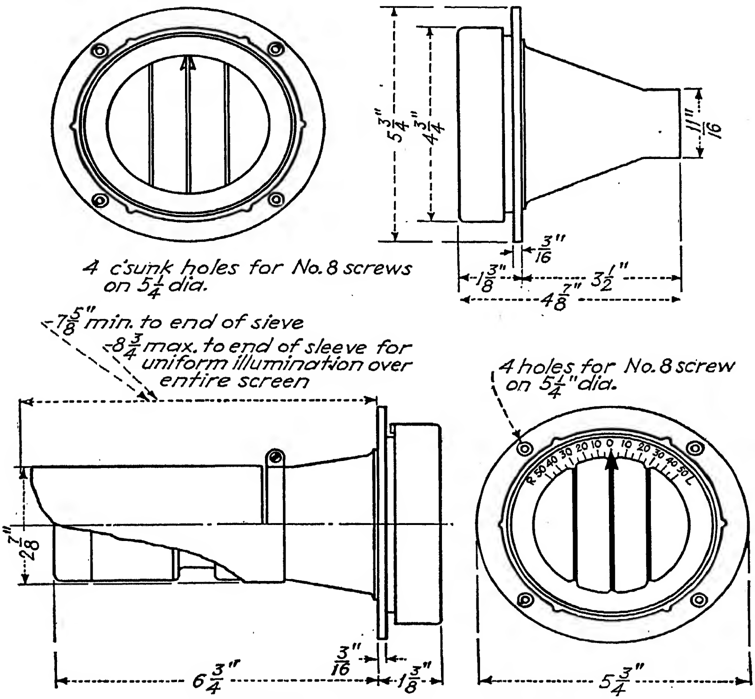


Fig. 63.—Installations diagram of Pioneer drift indicator.

LEARADIO AUTOMATIC DIRECTION FINDER

This is a comparatively new device by Lear Avia, Inc., Dayton, Ohio. It consists of a radio receiver and a visual automatic indicating, unilateral direction finder.

It has nine independent units and its inspection, maintenance, and repair belong in the field of radio engineering and mechanics. For this reason no detailed description or service instructions are given here.

SPERRY GYRO-HORIZON AND DIRECTIONAL GYRO

If poor visibility prevents the pilot from seeing the horizon, his sense of balance is confused and he can rarely keep his plane level. To make level flying possible in bad weather, the Sperry artificial horizon was designed and built.

This is now called the "gyro-horizon" because a gyro-actuated bar gives the pilot a line representing the horizon, which is kept level by a small gyro. In the center of this line is a miniature airplane.

In Fig. 64 are shown nine positions of the gyro-horizon and the plane, the center showing normal, level flight. The flight conditions are given under each cut and a little study will show just how they tell the story of each condition illustrated.

When it is recalled that rapid spinning tends to maintain the gyro's position regardless of the movements of the plane, Figs. 65, 66, 67, and 68 show

Fig. 64.—Gyro-horizon in nine positions.

its operation. The gyro spins about its vertical axis ZZ, while the mechanism of the instrument is mounted in the case, pivoted about the rolling axis XX. The housing (1) is carried on pivots in the gimbal ring (4) and free about the axis YY. The bar (2), representing the horizon, is carried on an arm pivoted at (5) and is controlled by the gyro through the guide pin (3).

When the plane noses up, as in Fig. 66, the plane of the gyro remains horizontal, which makes the horizon bar go down. This is reversed in Fig. 67. When the plane banks, only the instrument case and the small plane are carried with it, the rest of the instrument remaining level as in Fig. 68. These illustrations make it clear how the instrument gives the various indications shown in Fig. 64.

Four vanes, *A* (Fig. 69) are hung from the lower side of the gyro housing, each partly covering one of the four air ports *B* that exhaust air from the gyro housing. If the gyro tends to leave its vertical position during straight flight, gravity keeps the vanes vertical, and one vane closes the port on one side while the opposite vane opens its port, as shown. The reaction of the air escaping from this port moves the gyro in the direction *C*, back to its normal position. This corrective movement *C*, which is at right angles to the air force, is characteristic of all gyros, and is called *precession*.

This *precession* is so slow that the swinging vanes in rough air cancel each other before they have time to displace the gyro axis from the true vertical. To prevent a wrong indication, a precession-retarding device, called a *spoiler ring*, not shown in Fig. 69, is used. When one of the pendulous vanes uncovers its port, most of the air emitted is intercepted by this spoiler ring and reduces the precession rate so that the effect on the gyro is very small.

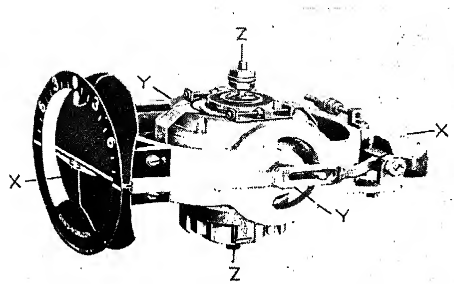


FIG. 65.—Gyro-horizon unit in level flight.

Maintenance.—If the gyro-horizon and the directional gyro are properly installed, they should not require overhaul in less than 300 or 400 hr. and should not require attention other than replacement of the filter during this period. Any trouble encountered will probably be due to a clogged filter, excessive vibration, or improper vacuum supply. For this reason it is recommended that a vacuum gage be installed with the gyro-horizon and the directional gyro to enable the user to determine at any time whether or not the instruments are operating under proper vacuum. The table of troubles, causes, and remedies shown on page 590, will assist in determining the cause of any malfunctioning of the gyro-horizon or the directional gyro.[1]

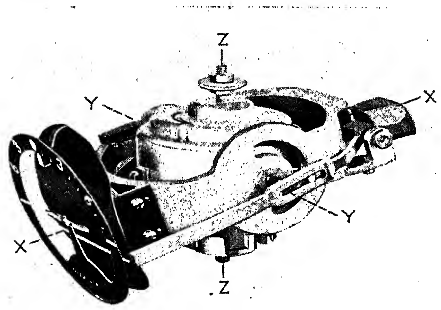


FIG. 66.—Gyro-horizon in climbing position.

Operating Principles and Description.—The object of the gyro-horizon and the directional gyro is to establish fixed references for maintaining flight attitude. The gyroscope (which is simply a spinning wheel mounted so its axle can be pointed in any direction) is used in both these instruments because it affords the best way of obtaining these references without exces-

[1] All tests to be made at cruising speed, cruising r.p.m., and in level flight.

sive size and weight. The gyros are air driven. The instrument cases are connected to venturi tubes or to a vacuum pump which maintains suction in the case, causing outside air to enter through a jet which drives the gyros.

Gyro-horizon

Troubles	Causes	Remedies
Bar fails to respond	1. No vacuum	1. Examine source of vacuum supply and tubing for leaks, stoppage, or pump failure
	2. Air filter disk dirty, reducing air flow	2. Examine filter disk at rear of instrument and replace if necessary
	3. Leaks in instrument case	3. See that all screws in instrument case are in place and tight
Bar does not settle level	1. Excessive vibration	1. Check instrument board with vibrometer and, if vibration is more than 0.004 in., apply shock absorbers in accordance with directions
	2. Low vacuum	2. Check vacuum in accordance with installation instructions
	3. Air filter disk dirty, reducing air flow	3. Examine filter disk at rear of instrument and replace if necessary
Bar oscillates or shimmies	1. Excessive vibration	1. Check instrument board with vibrometer and, if vibration is more than 0.004 in. apply shock absorbers in accordance with directions
	2. Vacuum too high	2. Check vacuum in accordance with installation instructions

The gyro-horizon derives its indication from a gyro spinning in a horizontal plane about a vertical axis Z (see Fig. 65). The mechanism of the instrument is mounted in the case, pivoted about the longitudinal (rolling) axis X. The gyro is contained in the housing which is carried on pivots in the gimbal ring so as to be free about the athwartships (pitching) axis Y. The horizon bar is carried on an arm pivoted at the rear of the gimbal ring and is controlled by the gyro through the guide pin. When the airplane noses up, as in Fig. 66, the plane of the gyro remains horizontal, causing the horizon bar to go down through its connection at the guide pin. Thus the miniature reference airplane in the instrument is above the bar, showing a nose high condition. Reverse action takes place (Fig. 67) in the case of a nose down condition. When the airplane banks, only the instrument case and the miniature airplane are carried with it, while the mechanism of gyro wheel, gimbal, and horizon bar remains level (Fig. 68).

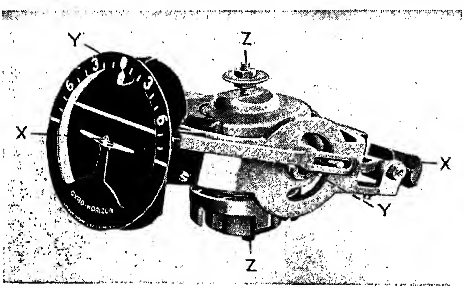


FIG. 67.—Gyro-horizon in a glide.

To keep the gyro axis upright, four pendulous vanes A are suspended from the underside of the gyro housing. Each one of these vanes partially covers

one of the four air ports *B* that exhaust air from the gyro housing. If the gyro tends to depart from its upright position during straight flight, gravity holds the vanes vertical and one vane closes one port while the opposite vane opens its port as shown in Fig. 69. The reaction of the air emitted from this open port moves the gyro in the direction *C* back to its normal position. The corrective movement *C*, which is at right angles to the air force, is called "precession" and is characteristic of all gyroscopes. The rate at which the gyro precesses in response to the action of the pendulous vanes is so slow that precessional forces created by the swinging of the vanes in rough air cancel one another before they have time to displace the gyro, and a true horizontal is established. A turn, especially of 180 deg., would tend to displace the gyro axis slightly from the true vertical, causing an erroneous indication of the horizon bar for a short time after the turn is completed. This is because the vanes, being pendulous, are affected by acceleration during the turn, with the result that the exhaust port on the side affected, instead of being opened partially, is opened completely, with consequent precession of the gyro away from the vertical axis. In order to prevent the instrument from giving an erroneous indication, a precession retarding device or spoiler ring is used. This ring is not shown in Fig 69. Whenever one of the exhaust ports is completely uncovered by its pendulous vane, as it would be during a turn or during erection to the vertical, most of the air which is being emitted, instead of reacting on the gyro, is intercepted by the spoiler ring. The precession rate is therefore reduced, and it follows that the effect on the gyro resulting from a turn is very small. As the error is almost imperceptible, the airplane can be leveled out safely by gyro-horizon indication when flying blind.

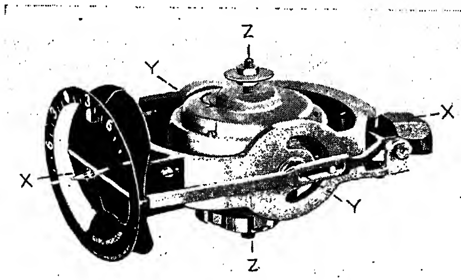


FIG. 68.—Gyro-horizon in a bank.

Directional Gyro

Troubles	Causes	Remedies
Dial spins continuously in one direction or drifts excessively in either direction	1. Excessive vibration	1. Check instrument board with vibrometer and, if vibration is more than 0.004 in., apply shock absorbers in accordance with directions
	2. Incorrect vacuum	2. Check vacuum in accordance with installation instructions. Should not be less than 3 in. Hg or more than 5 in. Hg
	3. Air filter disk dirty, reducing air flow	3. Examine filter disk at bottom of instrument and replace if necessary

Note: The gyro-horizon and the directional gyro should be operated on a vacuum supply of 3½ to 4 in. Hg. The rotor speed is approximately 12,000 r.p.m.

If the vacuum is found to be correct and vibration not excessive, and the trouble persists, the cause is probably due to worn pivots or bearings. In

such a case, the instrument should be removed from the airplane for inspection in accordance with the instructions under Lubrication and Inspection.

Under no condition should either the gyro-horizon or the directional gyro be taken apart by anyone not authorized to do so.

Removal of the air filter disk for renewing is not considered as disassembling the instrument and does not require removal of the instrument from the airplane.

To Renew Filter Disk (Gyro-horizon).—Lift out the snap ring that retains the filter disk at the rear of the case. Remove the filter disk and replace with a new one. New filter disks may be obtained from the Sperry Gyroscope Company, Inc.

To Renew Filter Disk (Directional Gyro).—Lift out the snap ring that retains the filter disk at the bottom of the case with a scribe. Replace the filter disk with a new one.

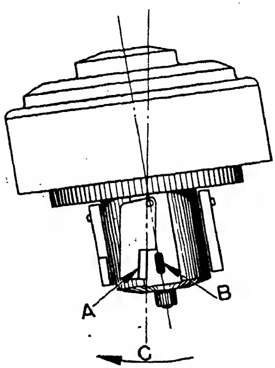


FIG. 69.—How the vanes act in flight.

Lubrication.—The shafts, pivots, and ball bearings of the instrument are lubricated before assembly in the case and, ordinarily, no further lubrication will be required. It should be borne in mind, however, that continuous use of the instrument in hot climates increases the evaporation of its oil, and replenishing may become necessary.

Inspection.—After every 300 to 400 hr. of operation it is advisable to have the instrument removed from the airplane and inspected, only, however, by an authorized instrument service station which has at its disposal the special tools and fixtures necessary for disassembly, inspection, and calibration of these instruments. Otherwise, the instrument should be returned to the Sperry Gyroscope Company, Inc., or their representative for inspection. For the gyro-horizon, insert the lock screw as shown in Fig. 70, unless the model has a caging device, in which case simply turn the knob to cage the gyro. For the directional gyro, be sure the caging knob is pushed *in*. Pack the instruments carefully, preferably in the same boxes in which they were received.

All gyro-horizons and directional gyros are carefully inspected before leaving the factory. They are shipped in packing cases specially designed to minimize the possibility of damage in transit. While in transit, however, the instruments may be subjected to conditions which are beyond the control of the company. Therefore, special instructions are given for inspecting and testing, with the recommendation that they be carefully followed if the instruments show any evidence of having been mishandled during shipment. The equipment necessary for making these tests is available at most air transport companies or at many service stations. It should be understood that conditions necessitating these tests are exceptional. Ordinarily, the purchaser may disregard them and proceed at once with the installation of the instrument.

After unpacking the instrument, remove the lock screw and replace it with the cadmium plated (white) case screw contained in the bag (see Fig. 70).

Note: This lock screw is not supplied with instruments having a caging

device. In this latter case merely turn the caging knob to free (uncage) the gyro.

Testing the Gyro-horizon.—Place the instrument on a testing block in a level position, and connect it to a vacuum pump and a manometer by means of rubber tubing. (The outlet not used must be kept plugged.) Adjust the miniature airplane by means of the knob at the bottom of the bezel until the wing is exactly in line with the indices at either side of the bezel.

Build up a vacuum slowly and when the manometer indicates that the vacuum has reached 3½ in. Hg, note the time required for the horizon bar to

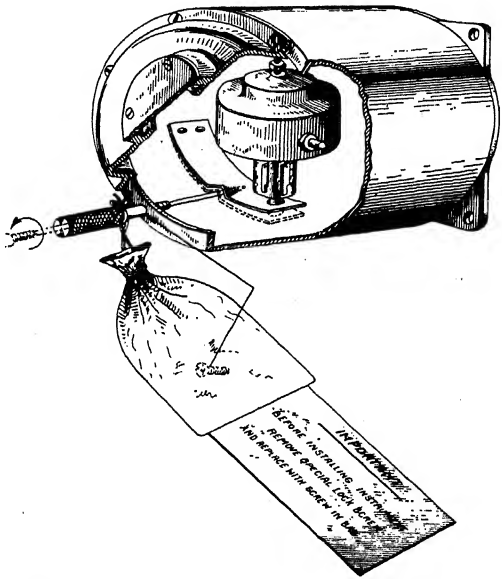


Fig. 70.—Replacing lock screw with special cadmium-plated screw.

reach the correct settling position as shown in Fig. 71. The horizon bar should be exactly in line with the indices at either side of the bezel. The time required will be proportional to the amount the horizon bar is displaced when the test is started. For instance, if the pointer at the top of the dial shows a 30-deg. tilt of the gyro, at least 6 min. will be required.

Continue to run the instrument at 3½ in. Hg, and at the expiration of 10 min. the horizon bar should be centered within the tolerances designated in Table 8.

If the bar should fail to settle as described, shut off the vacuum pump and allow the gyro to come to a full stop. See that the instrument is level in all directions and repeat the test. If the bar still fails to settle, the instrument has been damaged.

Note: Sometimes the bar will vibrate considerably when the instrument is first started. This vibration will stop as the gyro reaches normal speed.

If the horizon bar settles within the limits specified, the instrument is ready for installation.

Testing the Directional Gyro.—Place the directional gyro on the testing block in a level position and connect it exactly as described for the gyro-horizon.

Build up a vacuum slowly until the manometer indicates 3½ in. Hg. Then cage the instrument by pushing the caging knob *in*, and turn the caging knob to rotate the dial 360 deg. several times in both directions. This will prevent any tendency of the bearing to stick due to its inertia in transit.

Allow the instrument to run for at least 10 min.

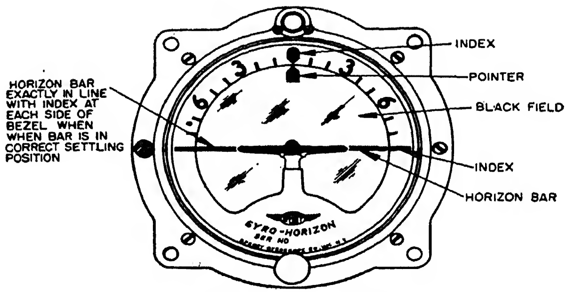


FIG. 71.—Settling position of gyro-horizon.

Set dial on 0 deg. heading and pull knob *out*, being careful not to disturb heading when doing so.

Operate the gyro for 20 min. on each of the following four headings: (1) card reading, 0; (2) card reading, 9; (3) card reading, 18; (4) card reading, 27.

Note the drift of the card every 5 min. The drift of the card, in azimuth, shall not exceed 3 deg., in either direction, for any 15 min. period for any of the stipulated headings. A maximum of 5 deg. drift is permitted on any one heading when the total drift of the four headings does not exceed 12 deg. See Table 8 for examples.

Table 8.—Test Card Readings

A		B		C	
Heading	Drift	Heading	Drift	Heading	Drift
0	−3	0	−3	0	−3
90	2	90	2	90	4
180	5	180	5	180	5
270	−2	270	−3	270	0
	Total 12 Acceptable		Total 13 Reject—excessive total		Total 12 Reject because of excessive drift on more than one point

If the instrument fails to come within the stipulated allowances described in the foregoing table, it will be permissible to make *two* repeat runs of the test that failed. This may be done immediately, or at the end of the group in which the failure occurred. *Two* out of the total of *three* runs must come within the stipulated limits to make the instrument acceptable.

To ensure a standard of testing, the vacuum must be maintained at 3½ in. and must not fluctuate more than ⅛ in. during tests. This applies to both the gyro-horizon and the directional gyro.

DIRECTIONAL GYRO

The directional gyro, in connection with the gyro-horizon, makes it possible for the pilot to rely on a good magnetic compass in blind flight. With the directional gyro to show when the plane is flying straight, the compass reading can be relied on. Without it, the slightest turn of the plane swings the compass card, and this does not disappear until *after* the plane has resumed a straight course. If the pilot follows the swing of the card, he turns the plane which increases the swing of the compass card.

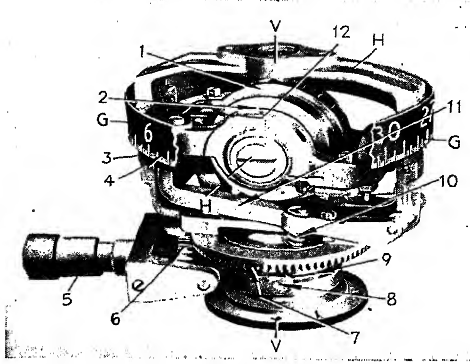


FIG. 72.—Principal parts of directional gyro.

The directional gyro does not swing. By watching the lubber line in relation to the card, the pilot can steer accurately on any given heading, even in rough air. The principal parts of the directional gyro are seen in Fig. 72. It is a horizontal, axis-free gyro, with an azimuth card and a setting device. The gyro, or rotor (1) spins on the horizontal axis H at about 10,000 r.p.m. It is supported in a gimbal ring (2) which is free to turn about the vertical axis G on bearings in the vertical ring (3). This vertical ring is free to turn about the vertical axis V. The graduated card (4), attached to the vertical ring, is seen by the pilot through an opening in the front of the case. A spinning gyro has the fundamental property of rigidity. So the rotor, gimbal ring, and card attached to the vertical ring remain fixed in azimuth and the plane moves around them. The card is read in relation to the lubber line, the same as a compass.

The *caging* knob (5) is used to set the directional gyro with the magnetic compass, and to reset it when necessary. When the knob is pushed in, it meshes the synchronizer pinion (6) with the gear (7).

Pushing the caging knob *in* engages the synchronizer lever plunger which normally rests in the cone-shaped interior of the pinion, and raises the lever pins (8) which slide in the groove (9) of the synchronizer ring. This lifts the synchronizer ring, pushing up the spring plungers (10) and raising the caging arm (11) so that it makes contact with the bottom of the gimbal ring and holds the gyro horizontal as the card is turned to the desired headway.

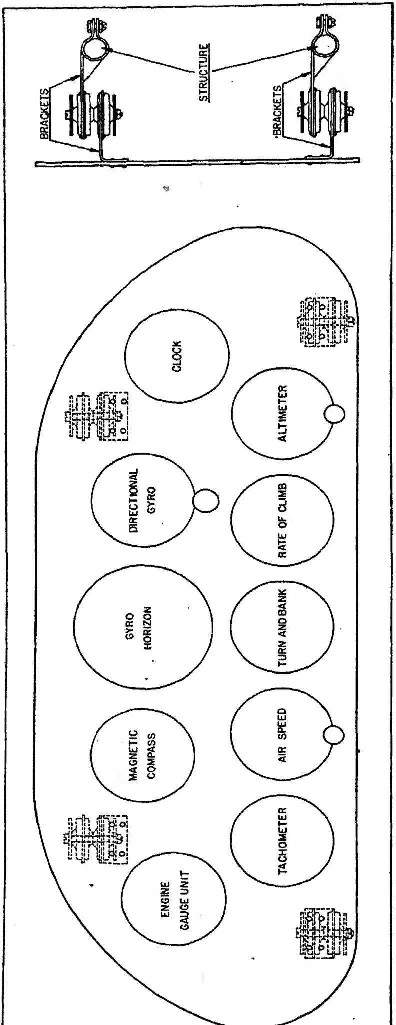


FIG. 73.—Shock-absorbing mounting of a complete instrument board.

Pulling the caging knob *out* releases the caging mechanism and leaves the gyro horizontal and free. The air jets of the nozzle (12) that spins the rotor, also serve to keep it upright. The air is divided into two parallel jets, each jet striking the bracket in the rim of the gyro at points equidistant from the center. If the rotor tilts, the air from the jet on one side strikes against the rim instead of against the brackets, and air from the other jets strikes the side of the brackets, causing the rotor to return to its upright position.

Careful design and workmanship give accuracy of balance and reduction of friction. This results in an instrument which, on the average, remains within 3 deg. of the original setting for at least 15 min.

Shock-absorbing Instrument Panels.—Gyroscopic instruments, like other devices, may give erroneous indications under abnormal vibratory conditions, and their useful life may also be materially affected. This is natural, as the ability of a gyroscope to perform satisfactorily lies in its perfection of balance about all axes, which, in turn, necessitates a very close fit between the gyro pivots, gimbal pivots, and their respective bearings. The longer these clearances are maintained the longer the useful life of the instrument will be. In the normal course of operation, the bearings will run true many hundreds of hours, because the loads to which they are subjected are relatively small.

Vibratory forces and the loads resulting therefrom are of constantly changing magnitude and in many cases changing direction. If a gyro is subjected to such forces, the bearings will come in contact

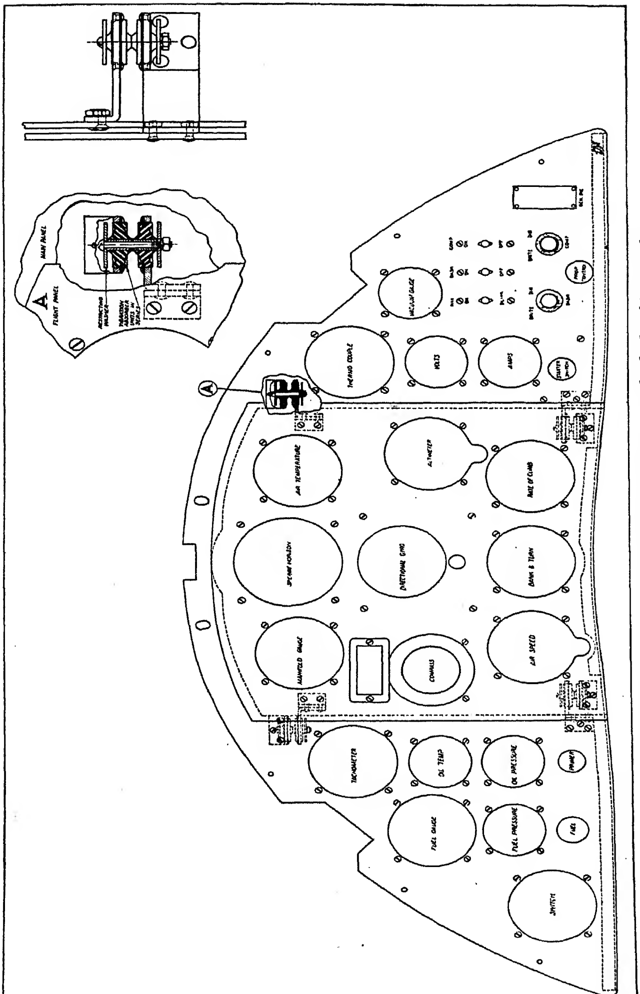


FIG. 74.—Large instrument board divided into separate shock-absorbing panels.

with their pivots at many different and varying points; the loads will not be evenly distributed, and high or low spots will develop, necessitating a premature overhaul of the instrument. As a result of tests and observations, it has been found, however, that vibration of less than 0.004 in. full amplitude produces such small additional loads that they can be ignored.

On airplanes that vibrate[1] (at cruising speed) more than 0.004 in. at the instrument board, the following special instructions should be carried out:

1. The instrument panel must be of sufficient thickness to overcome warping and flexing. The minimum panel thickness should be 0.125 in. for aluminum and 0.095 in. for dural. If the panel is large or long, it is sometimes necessary to add reinforcing ribs across the back of the panel as stiffeners.

2. Sponge rubber should never be used as a shock absorber. It varies greatly in its vibration characteristics as it ages. Even the best of it ages very rapidly when exposed to the varying atmospheric conditions encountered in flying.

3. Spring suspension is also inadvisable, as springs are not adapted to withstand violent acceleration forces.

4. The best shock absorbers are constructed of rubber which has been initially stressed in shear. A shock absorber made by the Lord Mfg. Co., Erie, Pa., or one similar to it, is recommended. Shock absorbers of this type reduce the amplitude of vibration as measured at the instrument board six to eight times. If the airplane itself is vibrating $\frac{1}{32}$ in., the vibration of the instrument board will be reduced to about $\frac{1}{240}$ in.

5. Shock absorbers should be mounted in a plane passing through the center of gravity of the panel. A very effective method of shock-absorbing a complete instrument board is seen in Fig. 73. Where the panel is large, it may be best to mount flight instruments on a separate, shock-absorbed panel, as in Fig. 74.

6. Select the size of shock absorbers by dividing the total weight of the panel (with instruments) by the number of suspension points to be used. *Two units are needed at each suspension point*, arranged in pairs, as shown. If a 16-lb. panel is to be suspended at *four* points, *eight* 4-lb. shock absorbers must be used. When the panel is mounted, the weight should deflect shock absorbers at least $\frac{1}{8}$ in.

7. All connections to the instrument board should be flexible, either rubber tubing or flexible metal hose.

Connecting the Instruments.—The size of tubing used in connecting instruments varies with the number of instruments and the length of tubing necessary. For a single instrument, where the tube is not over 12 ft. long, $\frac{3}{8}$ in. O.D. tubing should be used. From 12 to 25 ft., use $\frac{7}{16}$ O.D. tubing.

If, as in Fig. 75, a gyro-horizon, a directional gyro, and a third instrument, such as a turn and bank indicator, are installed, it is best to use a single tube between the instruments and the vacuum supply. For lengths up to 12 ft., use $\frac{1}{2}$ in. O.D. tubes; from 12 to 25 ft., use $\frac{5}{8}$ in. O.D. tubes.

A flexible connector is supplied for use between the metal tubing and the instruments. One end of this connector has a $\frac{1}{4}$-in. pipe thread which fits the instrument at whichever of the two outlets is more convenient. Plug the outlet that is not used.

[1] The Sperry Gyroscope Company, Inc., has developed a very accurate indicator with which the vibration of panels and other surfaces can readily be measured to an accuracy of 0.001 in. This instrument is available to users of Sperry aircraft instruments at cost.

Cut the tubing square and remove the burrs. Use standard flaring tools to get the proper fit in the tapered part of the fittings. Tighten the nuts carefully, but avoid excessive tightening.

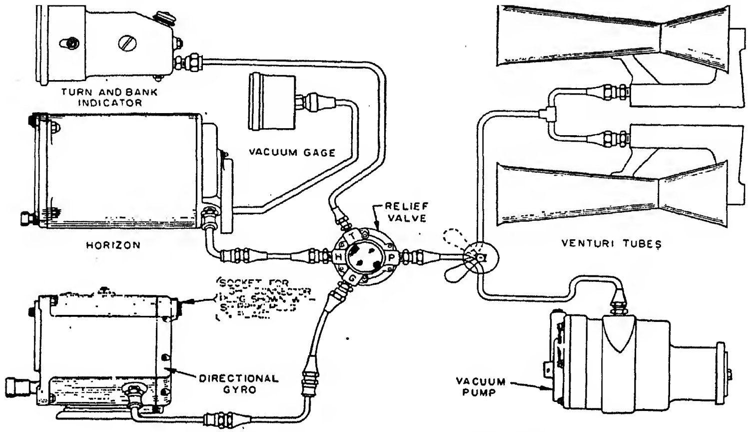


Fig. 75.—Connections for three instruments.

SPERRY GYROPILOT

The Sperry gyropilot, originally called the "automatic pilot," is the result of years of careful study and development. Experimental flights were made previous to 1914 by the late Lawrence Sperry, and continued intensively until sidetracked by the first World War. It has now been developed until it is standard equipment on all large transport planes, and for much military use.

Gyropilot equipment consists essentially of a directional gyro control unit, a bank and climb gyro control unit, a mounting unit, and a servo unit, with such accessories as are necessary for proper functioning of the equipment as a whole. It uses two gyros, one in the directional unit and one in the bank and climb unit. The first supplies reference for the rudder, the second for the ailerons and elevator.

Both of these gyros are the same as those used in the directional gyro and the gyro-horizon. In the gyropilot, however, their indications are utilized to secure corrective movements of the plane controls, through a simple pneumatic, hydraulic system.

In illustrating its operation only the aileron control by the bank and climb control unit will be used. The rudder and elevator controls are operated in the same way, by other connections.

With the plane flying level as in Fig. 76, the horizon bar on the dial of the gyropilot is level and the miniature plane parallel to it. The gyro remains fixed as the plane banks, the degree of movement being shown on the dial of the gyropilot, as at the top of Fig. 77.

The gyro is supported in a gimbal ring which has a disk with knife-edges attached to it. Air pick-offs AA' are enclosed in a box with the gyro ele-

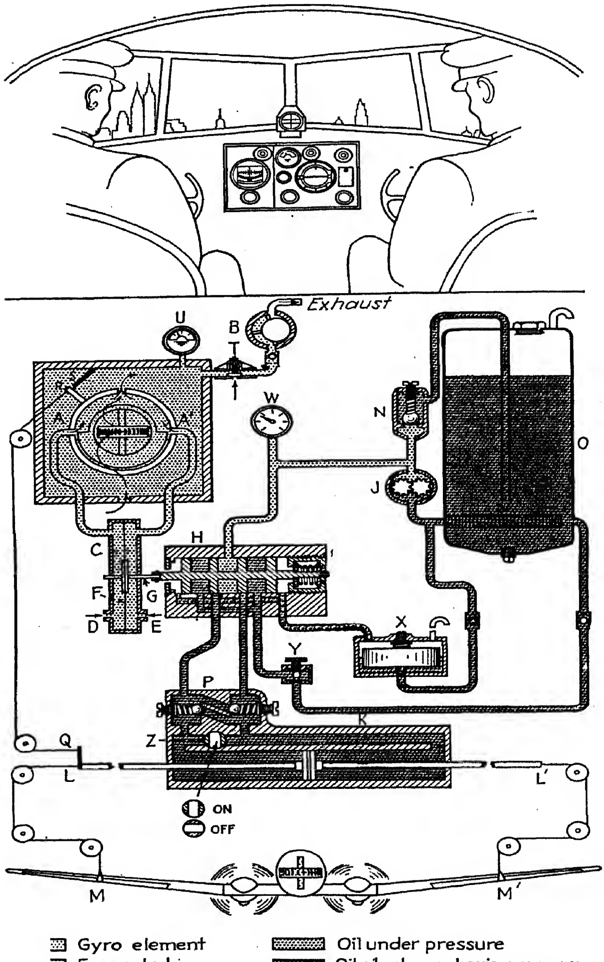


FIG. 76.—Diagram of gyro-pilot in level flight.

ment. Air is drawn into the bottom of the box by the suction pump B and led to the gyro to spin it. Air is also drawn in from the air relay C, through ports AA', and exhausted at the top.

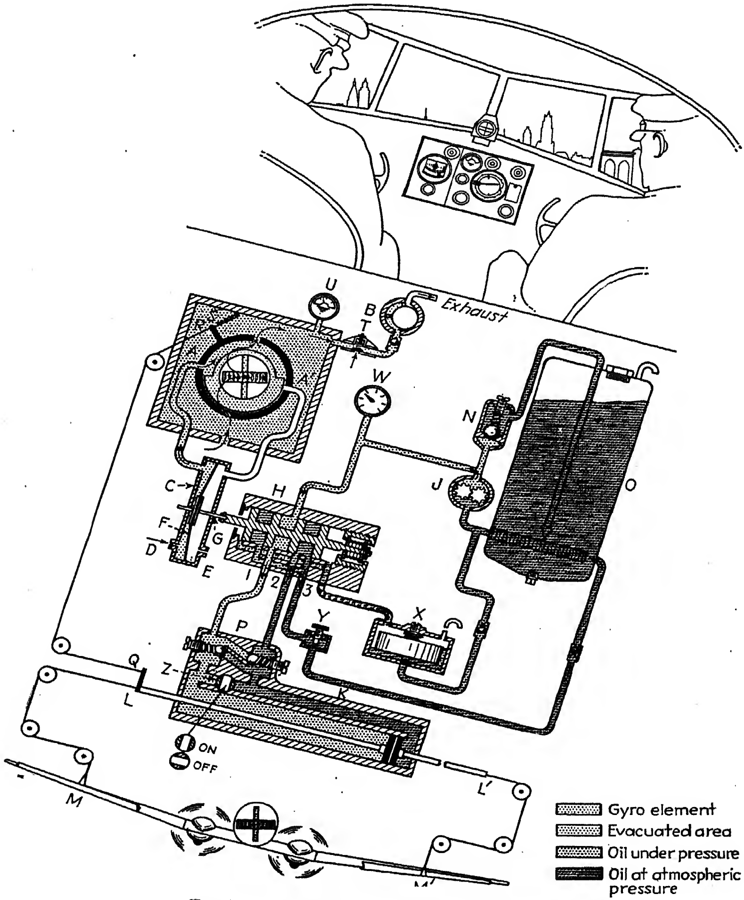


FIG. 77.—Same plane with right wing down.

Air relay C has two inlet ports D and E, on each side of diaphragm F, which is connected by piston rod G to the balanced oil valve H, in which a constant pressure is maintained by oil pump J.

As the balanced oil valve moves to the right or left to permit oil to flow to the servo unit *K*, the oil moves the piston rod *LL'* one way or the other. This piston rod is connected to the control cables that operate the ailerons *MM'*.

In Fig. 76 the gyro is upright and the knife-edges of the disk intercept an equal amount of air at both *D* and *E*. This maintains an equal suction on both sides of diaphragm *F*; the oil valve piston is in the center and no oil can flow to the servo cylinder. Pressure regulator *N* maintains oil pressure and permits any excess flow back to the oil sump.

With the plane's right wing down, as in Fig. 77, the gyro holds its vertical axis and port *A'* of the air pick-off system is closed. Suction on the left side of *F*, through port *A*, moves *F* to the left. The balanced oil valve moves in the same direction and oil flows through pipe 1 to the servo unit, passes around valve *P*, to the servo unit cylinder. This moves the piston to the right and applies power to the aileron control, restoring the plane to level flight. Oil from the other side of the piston returns to the balanced oil valve through pipe 2 and flows back to the oil sump, through pipe 3.

The "follow-up," an important part of the system, is also shown in Figs. 76 and 77. Its function is to remove the applied correction as the plane is returning to normal so that the control surface will be back in its normal position when the plane returns to level. The air pick-offs *AA'* are not fixed but can be moved by the follow-up mechanism. A cable connected to the servo piston rod at *Q* is attached to the lever *R* of the follow-up assembly. The follow-up movement is not shown, but the operation is as follows:

When the servo piston *LL'* moves to the right, the follow-up cable rotates the follow-up assembly against the pull of balance spring *S*, moving *A down* and *A' up*. When the ports reach a neutral position (both half open), the air relay and the balanced oil valve are centered; and the servo piston movement is stopped. As the plane continues toward normal attitude, the air pick-offs, which have been driven ahead of the gyro-box, pass beyond the neutral point and begin to cause servo movement in the opposite direction. This is not opposite control but rather the removal of the original control. The mechanism is so arranged that only the correct amount of control will be applied and also removed, at the proper rate as the plane returns to normal.

Figures 76 and 77 also show several accessories, such as *T*, a suction regulator which keeps the gyro spinning at the proper speed regardless of the speed of the suction pump; gage U shows the vacuum; sump *O* carries the reserve oil; a filter keeps the system clear of foreign matter; valve *N* automatically regulates oil pressure from the pump and permits circulation through the sump, when it is cut off from the servo unit; gage *W* shows the oil pressure.

Where the balanced oil valve is below the level of the sump, the drain trap *X* is used. It returns the drain oil from the balanced valve to the sump, the vent being carried to the top of the sump. Servo relief valves *P* permit the human pilot to overcome the gyropilot. Speed control valves *Y* regulate oil flow from the servo pistons and control the speed which the gyropilot operates the controls.

By-pass valve *Z* turns the gyropilot on and off. It has cable connections to allow the human pilot to fly the plane manually when he so desires. With the valve open the oil flows through the by-pass tube and the controls move easily.

Installation.—There must be drives and clearances on the engines for both the oil and vacuum pumps. When the servo unit is to be in series with the

control cables it is best to use the full servo piston stroke. If this is impossible due to the shortness of the control cable travel, a parallel system should be installed, with bell cranks, to utilize the full servo stroke. This is to prevent overcontrol oscillation which might result if minimum piston movement should produce too much angular deflection of the control surface. The units should be so installed as *to allow access for servicing.*

Location and Mounting of Units.—The mounting unit should be located in the center of the instrument panel or in front of one of the pilots, as high as possible, so that the faces of the directional gyro and bank and climb gyro

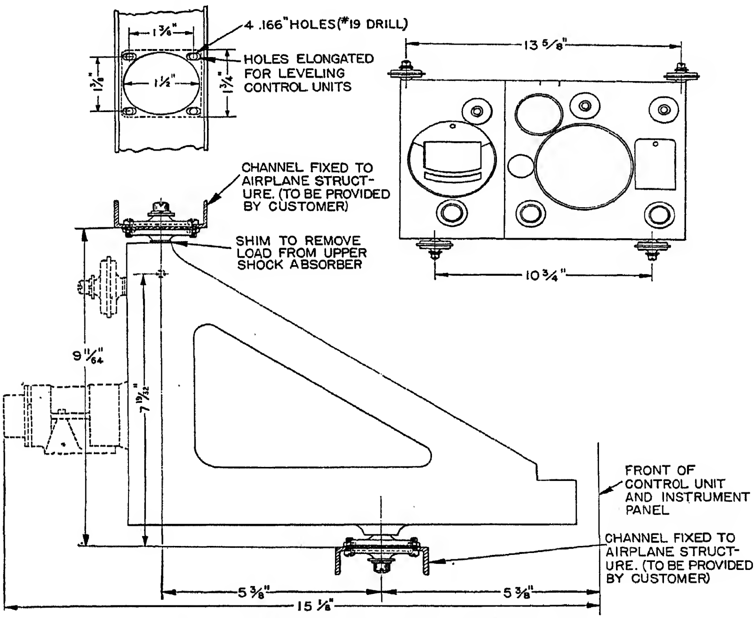


Fig. 78.—Suggested method of mounting gyro units.

control units will be flush with the instrument panel. There must be a clearance of at least 1/4 in. all around. A suggested method of installing the mounting unit is shown in Fig. 78.

The shock absorbers at the bottom of the mounting unit are fastened to a duralumin channel installed across the cockpit behind the instrument panel. The center line of the channel should be 5 3/8 in. back of the face of the panel. The shock absorbers attached to the top of the mounting unit should be fastened to an upper member to keep the unit balanced. The holes in the upper member should be elongated to permit leveling of the mounting unit. Practically the entire weight of the mounting unit and control units should be carried on the lower shock absorbers. It is also

important that the two gyro control units be easily seen by the pilot and their various control knobs easily reached. Clearance for removal of the gyro control units is also required. There must be access to the rear of the mounting unit to permit adjustment of the balanced oil valves and removal for cleaning.

The weight of the mounting unit, complete with control units, speed control valves, and oil gage is approximately 38 lb., and the center of gravity, laterally, is approximately 2 in. to the right of the center line, at the faces of the control units.

An alternate method of attaching the mounting unit where the entire instrument panel is shock-mounted is to remove the shock mounts from the mounting unit and attach the mounting unit at these points to brackets fastened to the back of the instrument panel. With this method it is not necessary to leave the ¼-in. cutout around the control units; leave only enough clearance for withdrawal from the panel.

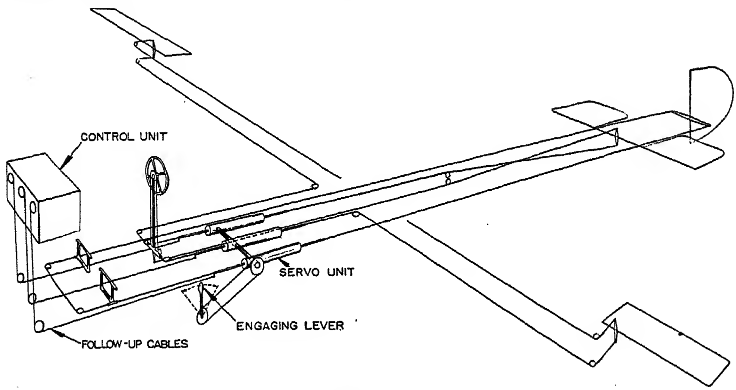


FIG. 79.—Cable connections with servo in series with main control system.

Servo speed control valves can be attached to the lower center of the mounting unit which will support it with the face of the speed control valves flush with the instrument panel face. The speed control valves can, however, be installed in some other position accessible to the pilot.

Oil pressure gage mounting dimensions are to the *small* A.N. standard for aircraft instruments. The gage can be attached to the mounting unit next to the speed control valves, or it may be installed on the main instrument panel convenient to the pilot.

The servo unit should be installed in the main control cables in series (Fig. 79) when possible. Where this is not feasible, a parallel type of installation should be used, as shown in Fig. 80. Servo rods can be used only in tension with cables. The equipment is not designed for use in compression. For either installation, brackets and structure to which the servo unit is attached must be sufficiently strong to withstand the design load of any two cables applied simultaneously (C.A.A. regulations). It is recommended that the servo unit be mounted in a horizontal position in order to preclude the possibility of trapping air in the cylinders.

The sump should be placed below the level of the mounting unit to permit gravity drain from the latter. If this is not possible, a drain trap must be used to ensure return of drainage oil to the hydraulic system. In no case should the sump be placed more than 5 ft. above the drain trap. It is also desirable that the sump be on a level with or above the oil pump to permit proper priming of the pump. But the primary consideration is to have gravity drainage from the mounting unit to the sump. The sump location should permit observance of the sight gage and accessibility for filling when the airplane is being serviced.

A vent line should be installed at one of the outlets on the top of the sump. On airplanes that are expected to perform acrobatics, the vent line should be carried down as far as the bottom of the sump on either the forward or aft side—preferably the latter. The structure to which the sump is attached should be sufficiently rigid so as not to vibrate excessively.

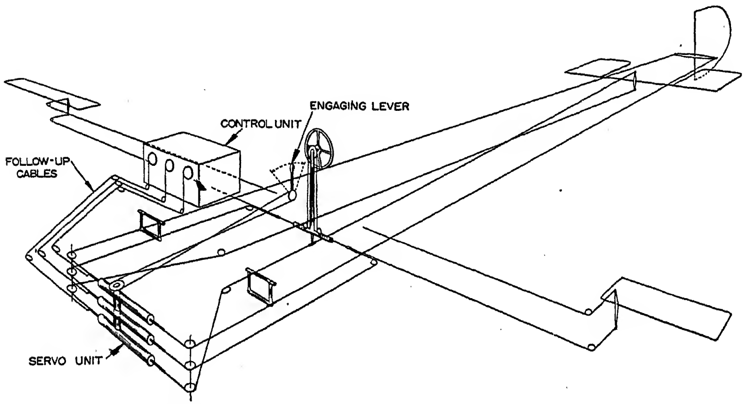


Fig. 80.—With servo cable connections paralleled into main control system.

Oil and vacuum pumps are installed on the drives provided for them on the aircraft engines.

The *vacuum relief valve* is located as close to the mounting unit as possible and so that it can be reached easily for adjustment and cleaning of the intake filter screen. It can be mounted on either end of the mounting unit, where mounting holes are provided, with air intake facing inboard. This allows access for cleaning the screen by removing the control units.

The *oil pressure regulator* is installed on the pressure side of the pump in a position to permit easy access to the adjusting screw and locknut. The desired hydraulic piping layout will govern the location of this unit to a certain extent.

The *oil filter* is located in the main oil pressure line between the pressure regulator and the balanced oil valves, and should be supported rigidly and installed so that the inner element can be easily removed for dismantling and cleaning.

The *drain trap*, when used, should be within 1 to 3 ft. of the mounting unit, sufficiently below the latter to provide good gravity flow from the drain

manifold and not more than 5 ft. below the oil sump location. Accessibility, sufficient suction in the oil intake line, and proper support are the only requirements governing the drain trap installation.

The *manifold block* should be mounted at the junction between the flexible oil line connections on the mounting unit and the rigid oil lines to the servo units.

Hookup of Units.—The *main cables*, attached to the ends of the servo unit piston rods, should have their pulleys and guides located so that no side loads will be exerted on the servo rods. Any cylinder can be used for any given control in either direction, the follow-up cables and tubing being connected to the proper places on the mounting unit. The ⅜-24 threads on the ends of the piston rods take a standard A.N. clevis. Stops should be provided in the airplane's control system set so that the servo unit is not employed as a stop at the end of its stroke. It is best to lay out the control system using the servo unit *in series* as shown in Fig. 79, as it generally reduces the amount of cable and pulley installation required. When necessary a parallel installation can be used as shown in Fig. 80, or a combination of series installation

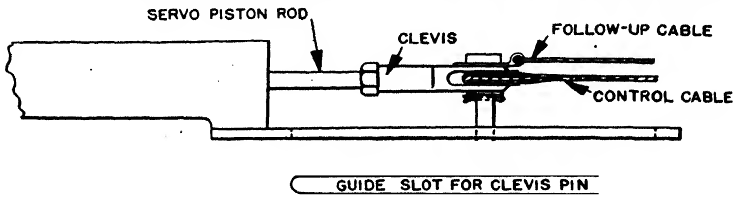


FIG. 81.—Suggested method of attaching cables.

for some controls and parallel for another. The rods of the servo have a tensile strength of 9,675 lb.

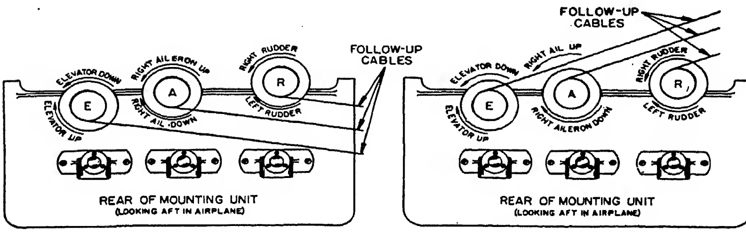
The *follow-up cables* should *in every case* be attached to the servo unit rods. Arrangements should be made so that the follow-up cables and the main cables cannot become twisted. A suggested method of using long bolts held by a slotted guide plate is shown in Fig. 81. The follow-up cables should be 1⁄16 in. diameter, 7 × 7 extra-flexible preformed cable. Use only ball-bearing aircraft pulleys of not less than 2 in. diameter between the cable attachment on the servo and the follow-up pulleys on the mounting unit. The follow-up cables should be protected by a guard at any place where they may be interfered with by crew, passengers, or material. Follow-up cables should be as short as possible and follow the most direct route from the servo to the mounting unit. These cables should never exceed 15 ft. in length. It is absolutely necessary to maintain the proper relation between the direction of control surface movement and the direction of rotation of the follow-up pulley. Follow-up pulleys move in one direction of rotation by the pull of the follow-up cable attached to the servo piston rod and in the other direction by a clock-type spiral spring in the follow-up pulley which keeps tension on the follow-up cable when the cable is moving toward the pulley. Follow-up pulleys can be furnished with the spring drive for either direction of rotation.

Cable attachment at the servos should be at the rod end providing the simplest cable run to the follow-up pulleys and the pulleys should then be selected to meet the following conditions (looking aft in the airplane at the follow-up pulleys on the mounting unit):

Rudder—Right rudder movement should produce counterclockwise rotation.
Aileron—Right aileron (right aileron up, left down) movement should produce counterclockwise rotation.
Elevator—Down elevator movement should produce counterclockwise rotation.

A suggested method for attachment is to mark the cable first at the place where it passes through the slot (with follow-up pulley wound up within one-quarter turn of its fully wound position). Then slide a small washer over the end of the cable, cut the cable close to the washer, bend the strands over the surface of the washer, and solder them securely.

After the cable has been attached, move the control slowly to the other extreme position. Check for smooth movement and to see that there is sufficient spring tension to hold the cable taut. Figure 82 shows the



SHOWING LEFT HAND PULLEYS

SHOWING RIGHT HAND PULLEYS

LEFT HAND FOLLOW-UP PULLEYS

NUMBER	SIZE-DIAMETER
150544	1"
150545	1 1/8"
150546	1 1/4"
150547	1 3/8"
150548	
150549	
150550	
150551	2"
150552	1/4"
150553	1/2"
150554	3/4"

NOTE
ANY COMBINATION OF LEFT OR RIGHT HAND PULLEYS MAY BE USED AS REQUIRED TO SIMPLIFY FOLLOW-UP CABLE INSTALLATION.

RIGHT HAND FOLLOW-UP PULLEYS

NUMBER	SIZE-DIAMETER
151391	1"
151392	1 1/8"
151393	1 1/4"
151394	1 3/8"
151395	1 1/2"
151396	1 5/8"
151397	1 3/4"
151398	2"
151399	2 1/4"
151400	2 1/2"
151401	2 3/4"

Fig. 82.—System of follow-up cables.

follow-up cable and pulley arrangements possible and designates which pulleys can be used for either direction of rotation.

The *on-off cable* should be attached to a lever convenient to the pilots and to the on-off pulley on the servo unit. Figure 82 shows the direction of rotation at the servo for on and off; $\frac{1}{16}$ in. 7×7 extra-preformed flexible cable should be used. The installation should be made in such a manner as to preclude any possibility of failure of the on-off system. Where a direct short run is possible from the servo to the hand lever, the pulley on the servo may be replaced by a lever and a direct push-pull rod may be used.

Hydraulic System.—The reliability of the gyropilot installation will depend to a large extent on the quality of the hydraulic installation with regard to material, workmanship, and layout.

Material.—52-SO aluminum alloy tubing should be used. Standard flare-type fittings are recommended of forged duralumin wherever possible;

cast aluminum alloy when the forged type is not available. A good grade of thread lubricant for aluminum or dural should be used. Flexible hose should be used at points of vibration and at flexible mountings. *Do not use copper tubing, gasket cement, shellac or dope, or rubber tubing.*

Workmanship.—Chips, filings, or dirt must not be permitted to enter the piping of either the hydraulic system or the air system. Fit each section of piping separately, cut the ends off square, and remove all burrs. Use stand-

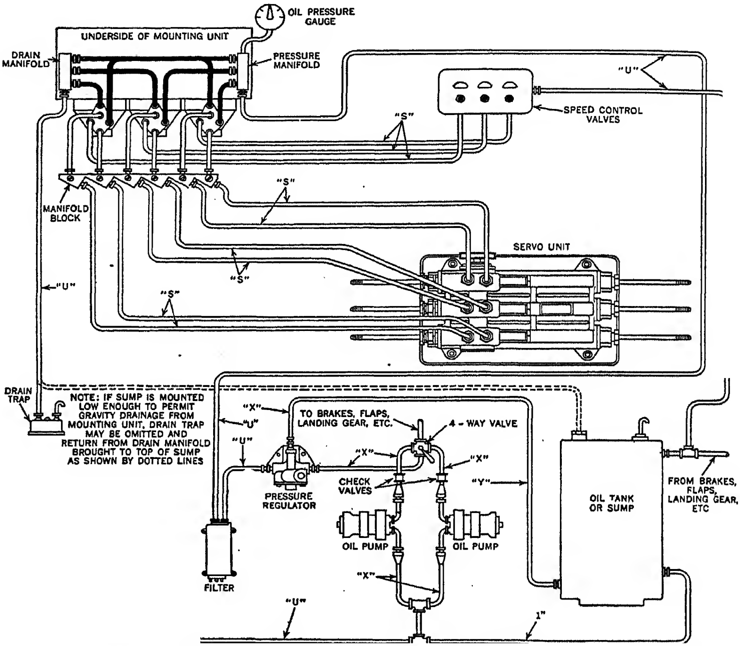


FIG. 83.—Hydraulic system with sump common to both gyro-pilot and other auxiliary equipment.

ard flaring tools to obtain a proper fit with the tapered portion of the fittings. *Too much vigilance cannot be exercised to see that the tubing is properly flared.*

Important.—Before making any connections of any section of the piping, wash out each piece of piping separately by pumping gasoline, kerosene, or carbon tetrachloride through it, and blow out with compressed air. Care must be exercised in applying the thread lubricant to prevent this material from getting into the system. Coat the fitting evenly all around and wipe off excess lubricant before assembling.

When making connections, tighten the nuts carefully. Excessive tightening will damage the flared end of the tubing and cause leaks. Be sure that all joints are tight and that all tubing is secured to eliminate vibration.

Chafing against any structure may cause a leak at a later date. Avoid right-angle bends as much as possible as these restrict the flow of air or oil within the tubing.

Layout.—Figures 83 and 84 show the basic hydraulic system layouts. Figure 83 shows a hydraulic system with a sump which is common to both the gyropilot and the airplane's auxiliary hydraulic equipment. Figure 84 shows the use of a single oil pump. Details of the complete equipment can be had from the makers.

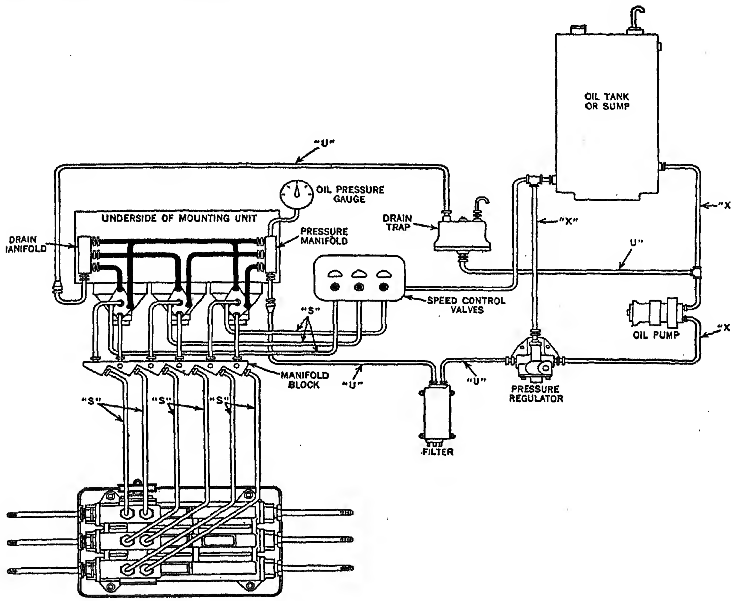


FIG. 84.—Hydraulic system with single oil pump and drain trap.

Air System.—The range of engine speeds and altitudes through which the gyropilot will operate will depend entirely on the air system installation. The vacuum pump pulls air from the gyropilot in order to maintain a reduced pressure (suction) in the equipment. The suction causes outside air to flow into the equipment through filters to operate the gyros, the air pick-offs, air relays, and air motor. A suction of 3.5 to 5.0 in. Hg is required to produce satisfactory operation of the equipment. Pumps supplied or recommended by Sperry will maintain this suction at 1,000 to 1,200 engine r.p.m. up to 5,000 ft., barometric altitude, and at engine cruising r.p.m. at the service ceiling of the airplane. To obtain these results, however, it is absolutely necessary that the drop in the system between the gyropilot and the vacuum pump be such as to require a suction of not more than 7 in. Hg at the vacuum pump. The curve chart of Fig. 85 shows the maximum

straight lengths without fittings of various sizes of tubing that can be used and still maintain the conditions mentioned above. Table 9 lists the drop produced by various types of fittings, expressed in terms of length of tube of the same nominal size which would produce an equivalent drop.

Table 9.—Length of Straight Tube

	Tube size equivalent (feet) to:	
O.D., in.	90-deg. elbow	Remarks
¼ × 0.035 wall	0.30	T and gross fittings have losses considerably above the elbow losses. Y-type fittings are preferable for manifolding. Where check valves are used, they should be of the flap type which have low equivalent line loss. Good judgment should be used so as not to underestimate fitting losses in an installation.
⅜ × 0.035 wall	0.48	
½ × 0.035 wall	0.67	
⅝ × 0.035 wall	0.86	
¾ × 0.035 wall	1.05	

Vacuum system requirements for gyropilot service ceiling of 20,000 ft.[1] are expressed in straight lengths of tubing.

Note: For any given length and size of vacuum-line tubing, the vacuum pump must have performance characteristics equal to, or greater than, figures shown in the bottom scales. This performance at pump speed is equivalent to engine cruising speed.

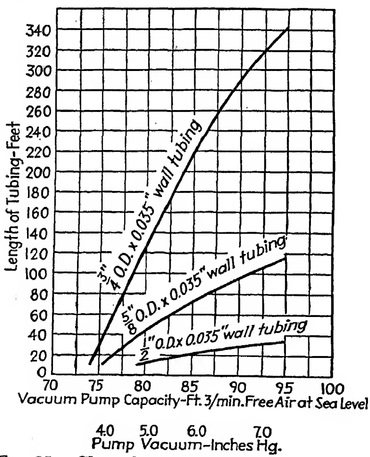


FIG. 85.—Chart showing requirements of system.

The vacuum system is shown diagrammatically in Fig. 86. A few simple rules to follow in planning the air system are listed:

Avoid the use of 90-deg. elbows. They cause a large vacuum drop and may force you to use a larger sized tubing than would otherwise be necessary. Use straight unions wherever joints are necessary. Keep the system as simple as possible, especially where there is a duplication of equipment and more than one pump is used. If any doubt exists, use the next larger size of tubing and fittings. It will call for less load on the pump and will allow more reserve for altitude operation. Fasten the tubing securely with clips or brackets, avoiding the use of friction tape.

Use only flap type check valves. Spring-loaded or ball type valves cause a high drop and overload the pumps. Locate the check valve as far from the pump as possible to provide a sufficient volume in which air may be compressed in the event that an engine kicks and runs backward a few turns. A check valve must be used to prevent damage to the gyropilot due to reverse running or oil discharge from a broken vacuum pump.

[1] For service ceiling of over 20,000 ft., consult the Sperry Gyroscope Co.

Electrical System.—Gyropilot units are lighted by a 12-volt bulb behind a hinged shield on the directional gyro control unit, and by two bulbs on the bank and climb unit. One is located behind the hinged instruction plate at the right of the dial, the other in a threaded socket at the left. In the

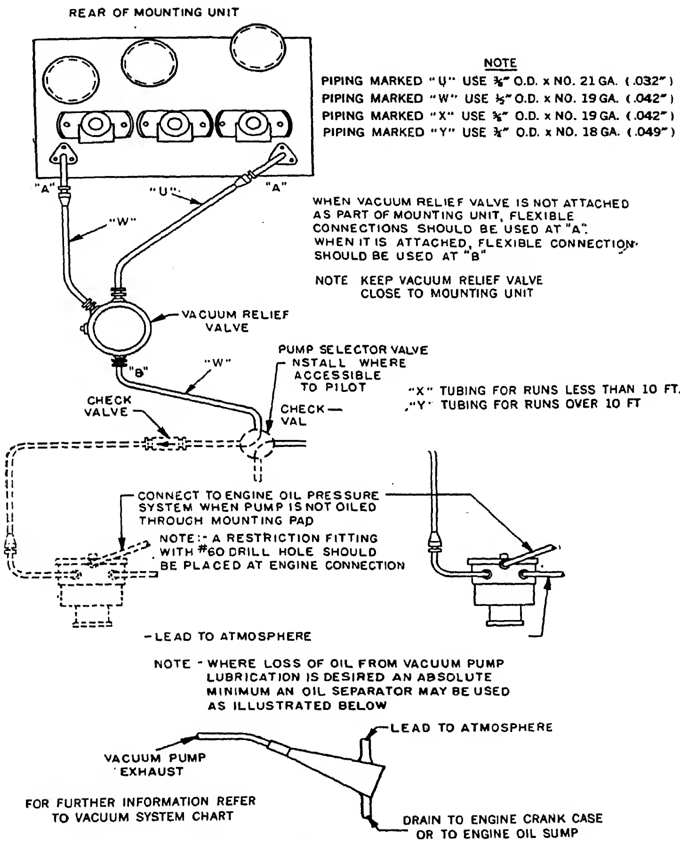


Fig. 86.—Diagram of a vacuum system.

bank and climb gyro electric connector on the back of the mounting unit are four poles: the top and bottom poles are for the lighting circuit; the horizontal poles are for the level flight temperature compensator. The latter should be connected to the master switch circuit, so that the compensator will be energized whenever the airplane is in use. The top and bottom poles

should be connected to the compass lighting circuit. Two spare bulbs are held in clips on the inside of the hinged instruction plate. All bulbs may be replaced without disturbing the operation of the instrument or the vacuum supply.

Maintenance. *Cleaning and Lubrication.*—The internal parts of the control units will require cleaning and oiling only at the 600 to 800-hr. check period when they are removed from the airplane and completely overhauled. The only other lubrication required in the entire system is to refill the sump and to oil the follow-up pulleys as directed in the 50 to 100-hr. check period.

Adjusting.—Adjustments to vacuum relief valve, oil pressure regulator, and other parts of the equipment are given where necessary under Trouble Shooting, page 617. Instructions for the adjustment of the servo relief valves and the balanced oil valves are given later.

Periodic Inspection and Maintenance.—Inspection and maintenance are to forestall trouble or failure by detecting maladjustment, wear, or weakness before it becomes serious. The inspection periods are only suggestive since their actual required frequency will depend largely on the service to which the apparatus is subjected.

50- *to* 100-*hr. Check.*—Inspect all piping and fittings including flexible hose. Tighten or replace fittings or pipes where necessary to stop leaks. Replace any flexible hose showing signs of seepage at the connections or pimples on the surface of the hose. Tighten the servo packing nuts if there is any leakage. Inspect all cables, cable connections, and pulleys. Main cables, follow-up cables, and servo on-off cables should be free working, positive, and free from any signs of fraying or wear.

Check follow-up pulleys on the mounting unit with gyro control units removed, and oil the springs, if dry. A few drops of engine oil are sufficient. Inspect and replace the air intake screens if necessary on the air relays, vacuum relief valve, and gyro control unit intakes. Check the oil in the sump tank; it should be three-fourths full. Use Sperry servo oil. It is specially prepared so as not to congeal at low temperatures.

Ground Test.—No gyropilot installation should be flown until it has passed a satisfactory ground test. An installation that does not check satisfactorily on the ground cannot be expected to perform satisfactorily in the air. The ground test will catch any reversed connections not caught during the installation inspection.

Fill the oil sump tank three-fourths full, close the speed control valves, and turn the gyropilot *off*.

Run the engine at 600 to 700 r.p.m. and note whether the oil pressure gage and the vacuum gage indicate. Within 1 or 2 min. the oil pump should prime and indicate pressure. *Do not allow the pump to run dry more than 5 min.* After it is certain that vacuum and oil pumps are operating, run at 1,000 r.p.m. and set the vacuum regulator for 4½ in. Hg at the gage *with level flight knob turned off* and the oil pressure regulator for the pressure it is believed will prove satisfactory. The speed valves should be closed while the oil pressure adjustment is being made.

The vacuum should not be less than 3 in. Hg at 1,000 r.p.m. with the level flight knob turned to *level*, or more than 5 in. Hg with the engine at maximum ground r.p.m. with the level flight knob turned to *off*.

Open the speed valves at least four turns; each numeral represents one turn of the knob.

Center the controls, align the follow-up indices, and then operate the controls manually, moving them slowly from hard over to hard over independently and collectively a few times. Then hold each control at each

extreme position for at least 30 sec. two or three times. This allows time for air in the servo to be pushed through the system by oil flow until it reaches the sump.

Shut down the engines for a few moments to check for air in the servos and replenish the oil in the sump which will have been passed on to the rest of the system. To check for air in the servos turn the gyropilot *on* (engines not running), in which case the controls should act as though locked. A resiliency indicates air in the servo which is compressed as force is applied to a control and which expands as force is removed. *Do not confuse stretching of the cable with air in the servo.* If any doubt exists, observe the indices on the control units for movement when checking for air. Fill the sump three-fourth full before continuung with the ground test.

Adjust the servo relief valves, in accordance with the instructions beginning at the bottom of this page.

Start the engines and run them at 1,000 r.p.m. Center all three controls, uncage the gyros, open the speed valves, align the follow-up indices with the gyro indications, turn the level control *off*, and turn the gyropilot *on*. All three controls should remain in position. (If the airplane is not level, the bank and climb gyro will move slowly toward the correct indication of the attitude of the airplane and cause the elevator and aileron controls to follow. The controls can then be recentered by rotating the hand control knobs.)

Check for *direction of control* movement by moving each setting knob back and forth a small amount, ascertaining that each control moves in the direction marked at the knob.

Check for control speed balance as follows: Open all three speed control valves wide. Turn the gyropilot *off* for a moment and move the aileron control hard over. Turn the gyropilot *on* quickly and count the seconds for the wheel or stick to come to neutral. Repeat from the opposite side. The time of return should coincide within 25 per cent. Follow the same procedure for the rudder and the elevator. Up elevator may be considerably slower than down elevator, especially on large airplanes due to the weight of the surface helping down movement and opposing up movement. **Caution.** Be sure that the tail of the airplane is not caused to rise when the elevator control is pushed all the way forward.

Check to be sure that the gyropilot can be overpowered with the gyropilot on.

If the above tests show proper operation the equipment is ready for the flight test. Should any faulty performance result, correct in accordance with Trouble Shooting, page 617.

300- *to* 400-*hour* (*Engine Overhaul*) *Period.*—Perform all operations called for in 50- to 100-hr. check. Remove the gyro control units and have a bench check made in the instrument shop. Overhaul if the performance is not satisfactory. Replace rubber grommets, if necessary.

Drain the oil sump. Remove the filter element from its housing, clean it in gasoline, and replace. Remove the oil and vacuum pumps. Wash them in gasoline and inspect the driving end for wear. Check the freedom of rotation. *Do not disassemble the pumps unless absolutely necessary.* If facilities are available, have the pumps checked for performance.

Inspect the shock-absorbing bushings on the mounting unit and replace them if necessary.

To Check Servo Relief Valves for Blowoff Pressure.—Conditions that govern the setting of the servo relief valves are (1) they should open readily in either direction without excessive manual effort to overpower the gyropilot, and (2) they should not open during normal flight conditions in smooth or

rough air. The best setting to meet these conditions will usually be found between 75 and 100 per cent of gyropilot operating pressure. To set the relief valves "tee in" two oil pressure gages of 300-lb. range, one in each line, to the servo cylinder at the point where the lines from the balanced oil valves are normally attached. If it is not convenient to connect the gages at the servo, connect them to the extra plugged outlets on the manifold block forward of the mounting unit.

Center the controls, align the follow-up indices, open the speed valves, and turn the gyropilot "on." See that the vacuum gage indication is normal, and that the oil pressure, as indicated by the gyropilot oil gage, is adjusted to give satisfactory operation under normal conditions.

Rotate the gyropilot hand control knob corresponding to the control being adjusted until the control surface has reached its stop. Continue rotating the control knob beyond this point until the follow-up indices are approximately 10 deg. apart. This will leave a signal on the control and

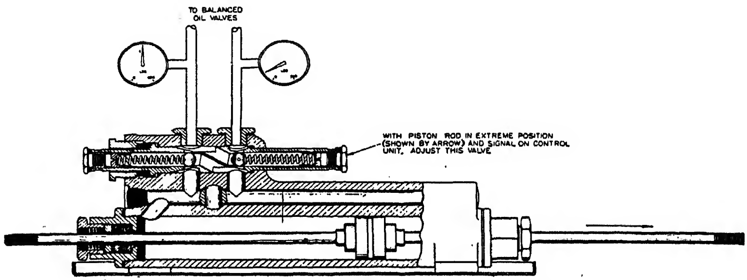


FIG. 87.—Servo unit. In this case, remove the right-hand nut.

hold the balanced oil valve open, thereby reducing the back pressure on the return side of the servo to a minimum. Note the readings on the test gages. Remove the hexagonal end cap at the end of the servo unit at which the greatest length of rod is visible (see Fig. 87). Unless the differential pressure (difference between the gage readings) is 75 per cent of the indicated gyropilot oil pressure, insert a screw driver and turn the adjusting screw. If the differential pressure is *lower*, turn the adjusting screw clockwise; if the same, turn it counterclockwise. Then replace the hexagonal cap.

Rotate the gyropilot control knob in the opposite direction to move the control surface hard over against the opposite stop. Adjust the other relief valve for the same servo cylinder in the manner just described.

To check the adjustment for each direction of control, rotate the control knob until the control surface is centered. Then manually overpower the control first one way and then the other, noting whether the differential pressures on the test gages are approximately equal for each direction of control movement. If it is found after flight tests that the valves open during normal flight conditions in smooth or rough air, it will be necessary to reset them to open at a differential pressure which will be a higher percentage of the gyropilot operating pressure.

When proper adjustments are obtained, work the air out of the system. Operate the controls manually a few times, to extreme positions. Then hold them in extreme position at least 30 sec., two or three times.

If it should be necessary to tighten the relief valve packing gland nut in order to prevent oil leakage, hold the relief valve tube with a wrench on the flats to keep the tube from turning.

Freedom of Balanced Oil Valves.—Check the freedom of the balanced oil valves and air relays, and the centralization of the balanced oil valves. The location of the balanced oil valves on the mounting unit is positively fixed. The air relays can be shifted slightly by the amount of clearance between the mounting holes and the mounting screws. After the balanced oil valve and air relay are both individually checked for free working, the air relay may be mounted loosely and shifted about on the screws until the two units together operate freely. Freedom of the two units can best be checked with the rear cover of the balanced oil valve removed. If the balanced oil valves are centralized properly, there should be no movement of a control with the gyropilot turned *on* (oil pump operating) and the gyro control units removed.

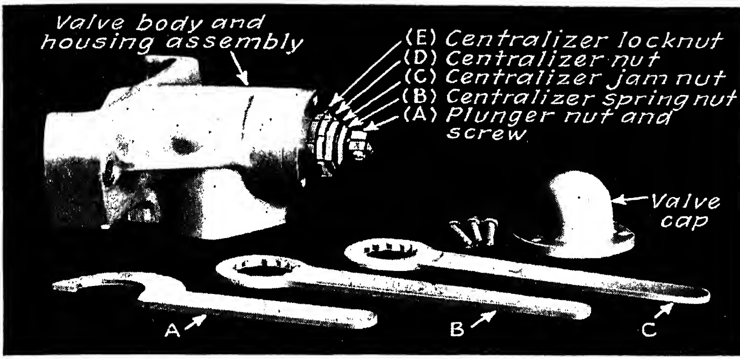


FIG. 88.—Balanced oil valve with cap removed and tools to be used.

Connect a rubber tube to one of the air relay connections. With oil pressure *on* and the Gyropilot engaging lever *on*, light suction and pressure should produce movement of the controls in each direction, which movement should cease when pressure or suction is removed. If the movement of the controls continues after the pressure or suction is removed, the balanced oil valves are not centralized. To centralize a balanced oil valve proceed as follows:

To centralize: With wrench, *A*, Fig. 88, loosen the centralizer lock nut *E*, Fig. 89, and adjust the centralizer nut *D* until corresponding control just starts to move in one direction. Mark the position of the centralizer nut with respect to the valve body; then turn in the opposite direction until the control starts to move in the opposite direction. Mark. Now turn the centralizer nut midway between the two markings, and tighten the centralizer lock nut. *Care must be taken not to disturb the plunger nut, spring nut, and jam nut, A, B and C.*

To adjust for end play: If there is end play or initial compression in a balanced oil valve, it will be necessary to remove the valve core assembly and readjust. To do this, first remove the air relay, being careful not to damage the shaft when detaching it from the balanced oil valve core. Loosen the

centralizer lock nut E with wrench A and back out the valve core assembly by turning the centralizer nut D counterclockwise. With wrench B loosen the centralizer jam nut C while holding the centralizer spring nut B with wrench C. Screw the centralizer spring nut and jam nut assembly *out* until there is noticeable play; then screw the assembly *in* until the end play just disappears. Tighten the centralizer jam nut with wrench B, while holding the centralizer spring nut with C and centralizer nut D with wrench A.

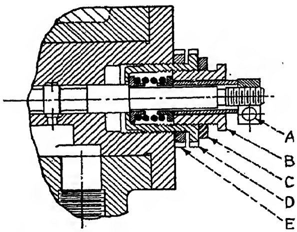


FIG. 89.—Cross section of balanced oil valve.

Loosen the plunger nut lock screw A (Fig. 89) and turn the plunger nut counterclockwise until there is noticeable play between the plunger and the centralizing assembly; then screw the plunger nut in until end play just disappears. When these adjustments are completed, there must be *no play;* at the same time, the spring must be *under no initial compression.*

Replace the valve core assembly in the valve body and screw in the centralizer nut until the end of the valve core is flush with the air relay end of the valve body. Replace the air relay and centralize the balanced oil valve, as shown before.

600- *to* 800-*hr. Period.*—The operations that follow should be performed only by organizations trained in the overhaul of gyropilot equipment and having the necessary special tools and fixtures required.

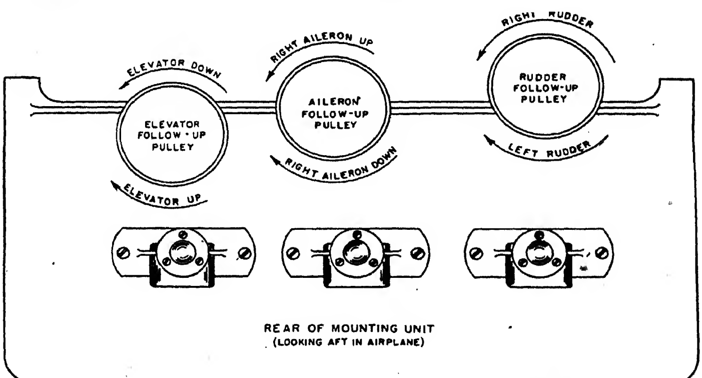


FIG. 90.—As the mounting unit appears looking aft in plane.

The following units should be removed and overhauled to put them in first-class operating condition:

a. Directional gyro control unit
b. Bank and climb gyro unit
c. Balanced oil valves
d. Oil sump
e. Pressure regulator
f. Oil filter
g. Oil pump
h. Vacuum pump

The following units should be removed and tested but not disassembled for overhaul, if their performance is satisfactory:

Air relays
Speed control valves
Vacuum relief valve
Servo unit

The construction of these units is such that there is little chance of internal wear.

Reinstall all units and make all checks given for the more frequent periods. Ground-test as previously noted.

In order to obtain ground test at all, it is necessary to have the proper vacuum, oil in the sump, and oil pressure. Possible causes of vacuum and oil troubles are listed below and followed by other troubles that might occur when vacuum and oil pressure are sufficient.

Figure 90 shows the rear of the mounting unit.

Trouble Shooting

Low or No Vacuum (under 3 in. Hg)

Causes	Remedies
a. Vacuum relief valve set too low.	*a.* Screw *in* adjusting screw. If increased vacuum does not result, valve is defective or trouble lies elsewhere. If vacuum does not jump with hand held over air intake of valve, trouble is definitely elsewhere.
b. Pump failure.	*b.* Repair or replace pump. Be sure that some other defect in the installation is not responsible for pump failure.
c. Leak or break in vacuum line.	*c.* Locate and repair.
d. Obstruction in vacuum line (may be collapsed inner wall of flexible hose).	*d.* Locate and repair.
e. Excessive line drop.	*e.* Tee a suction gage into the pump end of the vacuum line. With a suction of 7 in. Hg at the pump, it should be possible to obtain 4 in. Hg at the gyropilot. (Vacuum at the pump should not exceed 10 in.) If there is evidence of excessive line drop, recheck the installation in accordance with vacuum system installation instructions.
f. Pump lines reversed. (If a check valve has not been installed, the control units will be damaged by oil from the pump discharge.)	*f.* Check installation and connect lines correctly.

Excessive Vacuum (over 5 in. Hg)

Causes	Remedies
a. Vacuum relief valve set too high.	*a.* Reset.
b. Air intake filters clogged.	*b.* Replace with new filters.
c. Vacuum relief valve stuck closed.	*c.* Remove screen and push valve free with finger. Replace screen. If sticking persists replace or repair.

Low or No Oil Pressure

Causes	Remedies
a. Insufficient oil in system.	*a.* Fill sump three-fourths full. After running engine 5 min. with servo speed control valves open, refill to make up for oil fed into the system.
b. Pressure regulator out of adjustment.	*b.* Adjust with speed valves closed. Remove cap and loosen lock nut. Screw *in* to raise pressure; *out* to lower pressure.
c. Pressure regulator dirty or defective.	*c.* Clean, or repair and readjust.
d. Pump intake line or filter clogged.	*d.* Check line and filter.
e. Defective oil pump.	*e.* Test and replace if necessary.
f. By-pass valve open.	*f.* Close by-pass.
g. Broken line or leak.	*g.* Locate and repair.

Excessive Oil Pressure

Causes	Remedies
a. Oil pressure regulator set too high.	*a.* Adjust with speed valves closed. Remove cap and loosen locknut. Screw *out* to reduce pressure.
b. Oil pressure regulator stuck.	*b.* Clean and readjust.

Foaming of Oil

Foaming of oil is invariably caused by a leak in the line leading from the sump to the oil pump inlet or by a leak in the pump itself. In either case, the leak is not usually externally apparent. Being on the suction side of the system, *air* leaks *in* instead of *oil* leaking *out*. Air mixes with the oil, creating a foam that is of much greater volume than the oil itself. The excess volume is discharged from the sump vent causing loss of oil from the system.

No Operation of Any Control

Failure to operate all three controls in either direction can be attributed to the following causes:

a. Low or no oil pressure.	*a.* See Low or No Oil Pressure.
b. Low or no vacuum.	*b.* See Low or No Vacuum.
c. Engaging lever *off*.	*c.* Set to *on*.
d. Gyropilot *off* due to reversed or broken connection between *on-off* control and	*d.* Check for full 90-deg. throw of valve at servo. With engines not running, controls should be free with gyropilot *off* and feel locked with gyropilot *on*.
e. Speed control valves closed.	*e.* Open speed control valves 2 to 4 turns.

Failure of One of the Controls

a. Speed valve closed.	*a.* Open speed valve.
b. Servo relief valve by-passing.	*b.* Reset valve in accordance with instructions.
c. Oil valve stuck.	*c.* Remove rear cap and work valve back and forth by hand.
d. Air relay filter clogged.	*d.* Replace filter.
e. Defective control unit (*Note:* If light sucking and blowing on the air relay produces control operation, the trouble is probably in the control unit.)	*e.* Replace; examine control unit for condition of rubber grommets at rear.
f. Air relay stuck.	*f.* Clean or replace.

Controls Hunting

a. Air in oil system.	*a.* Move controls back and forth manually with engine running and gyropilot *off*. Hold each control at one and then the other extreme position for 1 min. This permits continuous flow of oil down one servo line, through the by-pass, and into the other line thus carrying any air back to the sump via the exhaust line. The follow-up indices should be set neutral at the start with the controls at neutral.
b. Lag in follow-up cable hookup caused by friction which would eventually return the follow-up to datum too late and cause overtravel, thereby reversing control.	*b.* Examine follow-up system cable and pulleys to see that follow-up indices are dead beat with controls. Remove any lag present.
c. Sticking oil valve.	*c.* Work valve manually until free—then hold at each extreme position for about 2 min. to allow any dirt to be carried back to the sump. This is to be done with Gyropilot engaging lever in *off* position.
d. Unbalanced oil valve.	*d.* Reset valve to neutral. (See Centralizing, page 615.)
e. End play in oil valve.	*e.* Reset balanced oil valve in accordance with instructions.
f. Gyros caged. A caged gyro will precess back and forth against the caging stops causing the controls to follow.	*f.* Uncage gyros.
Incorrect speed valve adjustment for the particular airplane or air condition.	*g.* Reduce speed valve setting.

Jerky Control

Causes	Remedies
a. Sticking in follow-up pulleys.	*a.* Remove control boxes and check for lubrication and rust in spring and bearing.
b. Excess friction in follow-up cable between servo and follow-up pulleys.	*b.* Examine follow-up cable system and pulleys and free up.
c. Sticky balanced oil valve.	*c.* Free valve. Clean if necessary. Valve will have to be rebalanced if removed for cleaning.

Lagging Control in One Direction Only

a. Follow-up pulley not wound sufficiently.	*a.* Shorten follow-up cable so that when control is hard over in the direction to wind the spring, the spring will be within one-fourth turn of being wound tight.
b. Dirt in balanced oil valve restricting travel in one direction.	*b.* Free valve. Clean if necessary. Rebalance after reassembly.
c. Oil valve not properly balanced.	*c.* Balance oil valve with control units removed. Replace control unit and recheck. (See instructions on page 615.)
d. Unbalanced air cutoff in control unit.	*d.* Remove control unit and determine if control speed is equal in both directions when same pressure is applied to either side of air relay which would indicate trouble in the control unit. Check operation with a control unit known to be good. Repair or replace defective control unit.

Lagging Control in Both Directions

a. Speed control valves closed too much.	*a.* Open valves.
b. Oil pressure too low.	*b.* Reset pressure regulator to amount previously known to be satisfactory.
c. Oil supply choked.	*c.* Examine interior of flexible hose, especially suction line to pump. Check oil supply lines and oil filter and clean if necessary.
d. Vacuum too low to give full travel of a relay and balanced oil valve.	*d.* Adjust regulator to 4 in. Hg.
e. Clogged filters in air relays.	*e.* Make temporary test with filters removed. If operation is satisfactory, install new filters.
f. Servo relief valve set too low.	*f.* Check in accordance with instructions.

Control in One Direction Only

a. Balanced oil valve restricted by dirt.	*a.* Operate manually to check. Free and clean valve if cause of trouble.
b. One filter clogged on air relay.	*b.* Check with both filters removed.
c. Follow-up or piping reversed.	*c.* Connect according to correct diagram.
d. Air leak at air pick-off grommet between control unit and mounting bracket.	*d.* Install new grommet and check.

Control Moves to Extreme Position When Gyropilot Is Turned On

If this takes place, repeat a few times, turning the gyropilot *on* with the follow-up index first to one side and then to the other side of the gyro index. If the control always moves the same way, check as explained under Control in One Direction Only. If it moves either way, always to take the follow-up index away from the gyro index, check as follows:

a. Reversed connections between balanced oil valve and servo.	*a.* Check with diagram and correct.
b. Follow-up direction reversed.	*b.* Check with diagram and correct.

Reversed Control

Control moves in wrong direction in response to know movement (stopping with follow-up index matching gyro index).

This can be caused only by a reversed follow-up *plus* reversed connections between the balanced oil valve and the servo. Check both with diagram and correct.

Reversed Follow-up Cables

A reversed follow-up cable will cause a control to move in the wrong direction to one or the other extreme positions when the gyropilot is turned on. The follow-up pointer will move away from coincidence with the gyro indication instead of toward it. The connections

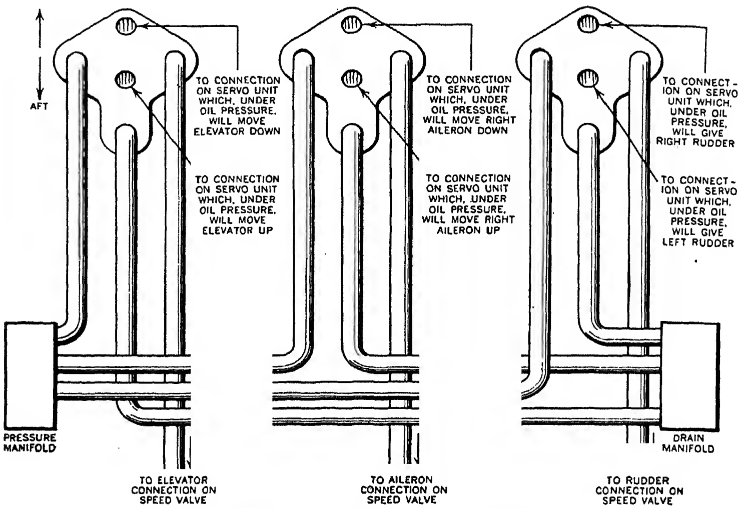


Fig. 91.—Diagram for checking hydraulic connections.

should be checked first at the follow-up pulleys, using the diagram shown in Fig. 79, and rechecked in the cockpit as follows:

Right rudder should move the follow-up card to the *left.*
Down elevator should move the follow-up pointer for climb and glide *up.*
Right aileron should move the follow-up pointer for bank to the *right.*

Reversed Servo Oil Lines

If the connections between a balanced oil valve and a servo cylinder are reversed, opposite control will result, continuing to the end of the control travel. The accompanying diagram (Fig. 91) should be used to check this portion of the system.

SECTION XVI

LANDING APPARATUS

LANDING GEARS

Airplane landing gears vary widely in design and construction to suit the different planes and the conditions under which they are used. Even on the light planes pneumatic-hydraulic shock absorbers have almost entirely replaced the rubber, or elastic, cords formerly used. Although these are still found to some extent on the small planes, they do not form the main dependence even there.

On the large planes that weigh 10 tons or more, the shock of landing ever so perfectly requires both structures and tires that can stand up under the

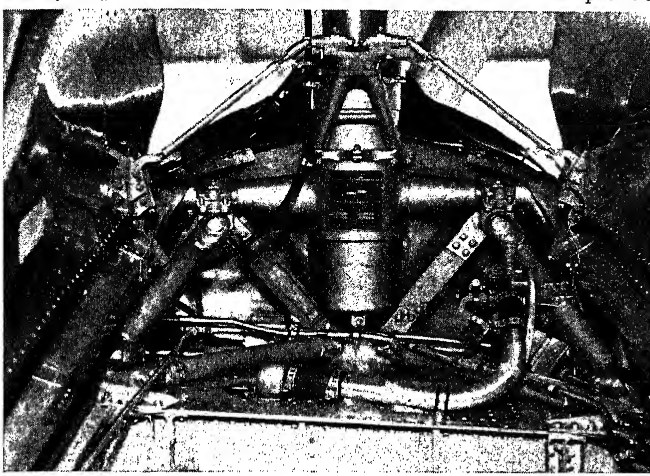


FIG. 1.—Landing-gear retracting mechanism and oil lines in wheel well of a Martin bomber. (*Courtesy of Glenn L. Martin Co.*)

strain. Add to this the mechanism necessary to retract the wheels and struts into the wells provided for them, and the problem becomes even more complex. Retractable gears are raised and lowered by hydraulic control.

In addition to the mechanism of the Glenn L. Martin bomber model 167 and the Bendix pneumatic struts by Bendix, the struts used on the small planes show how some landing gears are constructed.

Retractable landing gears require the most careful inspection and the greatest care in maintenance. The proper functioning of the mechanism

that raises and lowers the landing wheels is of vital importance both for the safety of the passengers and for the protection of the high-cost planes. The retraction of the wheels adds much to the speed of the plane; and this extra speed can be translated into pay load by reducing the power necessary to drive the plane through the air.

The Martin and the Bendix struts are shown herewith.

Retractable Landing Gears.—The use of retractable landing gears involves some very ingenious designing and requires construction that is sturdy, easily controlled, and dependable. There are, of course, numerous designs

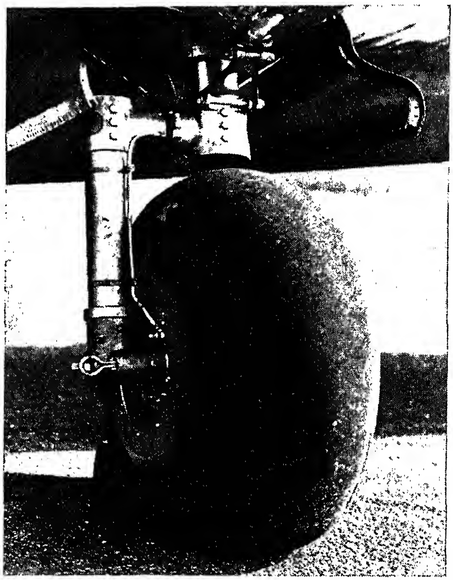


FIG. 2.—Offset strut that carries the wheel of a Martin bomber. (*Courtesy Glenn L. Martin Co.*)

both as to construction and operation. That of the Glenn L. Martin Co., for use on their heavy bombers, is an excellent example of design to secure the required strength with a minimum of weight. Figure 1 shows the landing gear retracting mechanism and the oil lines in the wheel wells of model 167 bomber.

This design has a single straight strut which carries the wheel on an axle on an offset member, as seen in Fig. 2. The strut carries a trunnion head that is supported in widely spaced bearings, shown in Fig. 1. The strut, with the wheel, swings on these trunnions, up into a well in the nacelle, as in Fig. 3, behind the engine. The action is hydraulically controlled.

As the wheel comes up into the well the hinged doors, seen on each side in all three views, close under the wheel and strut, leaving a smooth, stream-

lined surface. Figure 2 gives a good idea of the rigid construction of the axle support. It also shows the pipe line leading to the wheel brake.

Figure 3 shows the wheel and the underside of the plane. The doors that cover the wheel well in the underside of the fuselage, are shown hang-

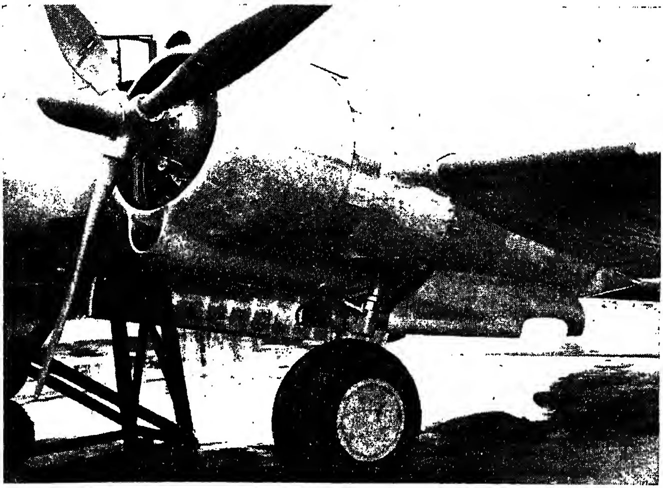


FIG. 3.—Landing gear and left-hand engine on Martin bomber model 167. (*Courtesy of Glenn L. Martin Co.*)

ing open. These close over the wheels when they are drawn up and make a smooth surface for the air to flow over when the plane is in flight.

Bendix Pneudraulic Shock Struts

Bendix shock struts combine pneumatic and hydraulic control. There are two telescoping chambers, as in Fig. 4, which also give the names of the various parts. The lower chamber is always filled with fluid, either that made for Bendix, or the Lockheed brake fluids, No. 5 or 21. No other should be used.

The upper chamber has compressed air in the upper end and fluid in the bottom, when in normal position. The fluid level must be level with the hole in the filler plug boss *A*, when the strut is fully compressed. This is checked by removing the filler plug. Do not remove the plug until all the air has been let out by depressing the valve cone, shown in Fig. 5. The amount of fluid varies in the different struts from 68 to 82 oz. and the air pressure from 50 to 60 lb.

Alignment between the inner and outer cylinders of the strut is maintained by the torque arms *Z*. The lower arms connect with the extension that carries the axle for the landing wheel. Air pressure need be measured only by the specified extension of the strut under full load. This extension is shown on the instruction plate of each strut.

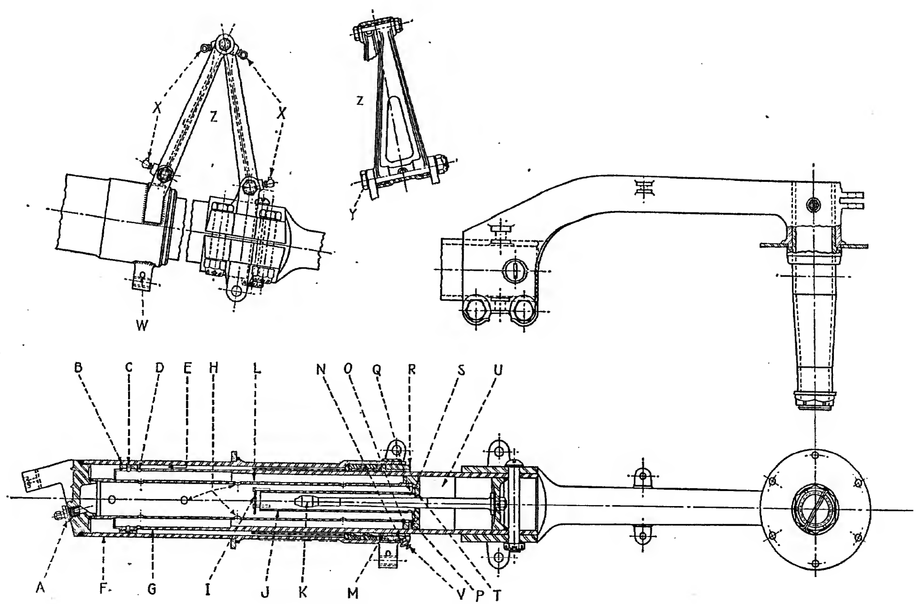


FIG. 4.—Bendix Pneudraulic shock struts.

A. Filler plug
B. Upper bronze bearing
C. Lock screw
D. Hole in inner cylinder
E. Annular chamber
F. Outer cylinder
G. Inner cylinder
H. Holes in tube *L*
I. Flap valve
J. Snubber tube
K. Metering pin
L. Piston tube
M. Lower bronze bearing
N. Lock screw
O. Bronze piston
P. Lock-screw hole
Q. Small holes in tube *J*
R. Bearing nut
S. Piston insert
T. Orifice into snubber tube
U. Lower chamber
V. Lock wire
W. Side-lug bushing
X. Torque-scissors grease fittings
Y. Scissors bolt
Z. Torque arms which maintain alignment

The impact energy of landing is absorbed by the strut fluid and by the compressed air. Taxi loads are carried mainly by the compressed air. The snubbing effect, which prevents quick rebounds, is secured by the strut oil's being forced through small orifices on the expansion stroke.

In the compression stroke, cylinder *G* moves into cylinder *F*, reducing the volume of chamber *U* and forcing the strut fluid through orifice *T* and into snubber tube *J*. This flow is controlled by the varying section of metering pin *K*. The fluid absorbs most of the impact energy in overcoming the resistance of flowing through *T*.

As the oil rises, it opens flap valve *I* on the end of tube *J* and compresses the air above it. As the oil level rises, some of it flows through holes *H* into chamber *E* through hole *D*. Compression stops when the entire impact load has been absorbed.

When the impact has been absorbed, the air in the upper chamber expands and extends the strut. Flap valve *I* is closed by the returning oil, which must then pass through the small holes *Q* in the lower end of tube *J*. The extension of the strut reduces the volume of chamber *E*, forcing the oil back through holes *H*, and finally through the lower chamber through the small holes *Q*. This slows up the expansion movement and reduces the rebound.

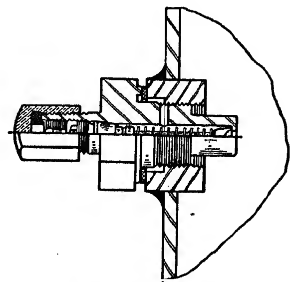


Fig. 5.—Construction of filler plug *A* (Fig. 4) and valve.

Installation.—In installing struts after they have been removed for inspection and overhaul, or in replacing struts, first lubricate them with a medium grade grease, using a gun.

Turn the struts right side up in a vertical position and extend fully.

Refill the struts with the correct amount of specified fluid by pouring it through the filler plug hole.

Move the strut through its full stroke two or three times and check the fluid level while the strut is in the vertical position and fully compressed.

Add more fluid, if needed, until the fluid is level with the filler plug hole.

Reinstall the copper gaskets and filler plug assembly.

Reassemble Struts to Airplane.—Attach the struts to the airplane by means of the strut fittings and connections.

Install the assembly consisting of tire, wheel, and brakes to the struts.

Inflate the tire and tube to the proper pressure.

Inflation of Shock Struts.—The plane should be placed in a hangar at the time the struts are inflated. It is impossible accurately to check the extension of the struts if the airplane is being subjected to wind forces or slip stream from the propeller.

The struts must be supporting the full normal load of the airplane when they are being inflated.

Force air into the struts by means of a pump or a high-pressure air bottle until the specified extension as shown on the instruction plate is obtained under full load.

The plane should be rocked occasionally while the struts are being inflated, to overcome packing friction and thus to prevent inadvertent overinflation.

If the strut is being inflated for the first time, the extension distance should be made approximately ¼ in. greater than specified, as moving the plane will cause some absorption of the air by the fluid.

A variation of not more than ¼ in. either way for check readings will not be considered of importance.

Alternate Method.—If it is more convenient to check pressures under a light load, the actual extension under the load can be noted after the strut has been properly inflated under the full load.

The extension of the struts may thereafter be checked against this new value provided they have the same light load previously established.

The same general procedure can be followed to inflate struts under the light load as outlined for the full-load conditions.

After the struts are once correctly adjusted, readjustments need not be made for minor changes as they may be due to change in position of plane, change of load, wind action, packing friction, rolling the plane backward, etc.

To Remove the Units.—Completely deflate the tire and remove the tire, wheel, and brakes from the struts.

Completely release all air from the strut by depressing the valve core. *Wait until all fizzing of air and fluid has stopped.*

It is important from a safety standpoint that all air under pressure be released before further handling. Do not completely remove filler plug assembly *A*.

Remove lock wire *V* and lock screw *N* from the bearing nut *R*. Loosen the bearing nut *R* with a spanner wrench but do not remove it. Remove the struts from the plane.

Inspection and Maintenance.—The life and satisfactory operation of shock struts are largely dependent upon the maintenance and operating conditions of the other component parts of the landing gear unit. Therefore, routine inspection of the wheels, tires, etc. should also be made.

Daily Visual Inspection.—Inspect the entire outside portion of the strut assembly especially in the locality of welds, lugs, connections, etc., for any evidence of cracks or indications of structural failure. If cracks or other unserviceable conditions are found, the strut assembly must be removed from the airplane, disassembled, and the unserviceable part replaced.

Inspect the chrome plating on the exposed outer wall of the inner cylinder for any evidence of corrosion, pitting, or scoring. If the plating is deteriorated or worn through at any point, the assembly must be removed, disassembled, and the piston tube replated.

Examine the cotter pins and safety wire on all nuts and lock screws and, at the same time, check the tightness of bolts, nuts, and screws. Safety wires must be replaced if broken and all loose bolts, nuts, and lock screws must be tightened.

Air Leaks.—Examine the air valve core for leaks by putting a small quantity of oil on the top of the valve. Air bubbles will form if the valve is leaking. If leakage is observed, depress the valve core and allow it to snap back. This will allow the valve to reseat itself. If this does not stop leakage the strut must be deflated and the valve core replaced. Inspect the filler plug assembly for air leaks by placing a small quantity of oil around the copper gasket. If leakage is apparent, deflate the strut, remove the filler plug assembly, and put in a new gasket.

Care must be taken in replacing the gasket, to be sure that both surfaces are free from dirt and marks, and that the plug is seated snugly.

Fluid Leaks.—Inspect for fluid leaks around the packing. A slight seepage of fluid, as is indicated by a film of fluid, is to be expected and should be

ignored. If fluid leakage around the packing is found to be serious, as will be shown by a collection of drops around the inner cylinder outside the packing, remove the lock wire from the bearing nut and tighten the nut one-quarter turn. If leakage continues, remove the strut, disassemble, and inspect for faulty packing, worn parts, etc.

Inspection of Strut Extension.—Check the strut for extension to the amount specified on the instruction plate. The struts must be checked under full load or under the load previously set up for such checking. Minor variations of the strut extension, up to ¼ in., may be disregarded. If more than this variation is noted or if the struts have been reported as striking top or bottom with ordinary usage, the fluid level must be checked.

When it is necessary to check the fluid level, deflate the strut. Depress the valve core and wait until all the air is exhausted. Care must be taken that all air is completely exhausted from the unit before any attempt is made to remove the filler plug assembly. Back off the filler plug one-quarter turn. Make certain that all "fizzing" of air and fluid has stopped before removing it completely.

Remove filler plug assembly and fully compress the strut. Check the fluid level. The fluid will be level with the filler plug hole if the strut is filled the required amount. Add more fluid, if needed, until the correct level is obtained. Replace the filler plug and reinflate the struts.

80-*hr. Inspection—Strut Lubrication.*—The lubrication of struts should be checked at regular 80-hr. periods, or oftener, depending upon operating conditions as mentioned previously.

Disassembly, Inspection, Repair, Reassembly, and Storage.—It is necessary to remove the units for inspection and overhaul, after certain intervals, depending upon service conditions and the operation of the struts. The performance of the shock struts bears a definite relationship to the condition of the other component members of the landing gear unit. So when inspecting and overhauling the struts, routine maintenance of the wheels, brakes, tires, etc. should be made. Suggestions outlined below may be followed in disassembly, inspection, repair, and reassembly of the struts. Figure 4 will make these clear.

Remove the shock strut assemblies from the plane, as previously described.

Disassembly.—Remove the filler plug assembly *A*. Invert the strut, pouring the liquid from it through the hydraulic inlet fitting hole.

Hold the strut at a 45-deg. angle and move the inner cylinder through its full stroke two or three times to eject all of the fluid. Disconnect the torque links from the lower cylinder by removing bolt *Y*. Back nut *R* completely off the cylinder.

Pull outward on the inner cylinder assembly until it comes entirely out of the cylinder. If necessary, use a slight bumping action to break the packing rings loose. Remove lock screw *C* from the bearing *B*.

Unscrew bearing *B* completely off the end of the inner cylinder. Slip the spacer tube, spacer ring, packing gland, and bearing nut off the upper end of the inner cylinder. Remove lock screw *P* from piston *O*. Unscrew piston *O* completely off the end of piston tube *L* to remove the piston and piston insert *S*.

Inspection and Repair.—Inspect all welded joints for evidence of cracks. If cracks are found, the part must be replaced.

Inspect the plating on the outer wall of the inner cylinder, as already mentioned.

Inspect the packing rings. If no longer serviceable, or if leakage has occurred, the packing must be replaced. It is recommended that it be changed at least once a year.

Inspect the valve core and copper gaskets of filler plug assembly. If the valve core has been reported as leaking or shows evidence of being damaged, it should be replaced with a new part. In general, valve cores will be replaced as often as the packing, at least once a year.

Examine the copper gasket for scratches and burrs. Gaskets must be replaced if they are damaged in any way likely to cause air leaks.

Inspect the inner wall of the outer cylinder for evidence of corrosion or scoring by inserting an inspection light into the interior of the cylinder. Slight corrosion or scoring is not serious, since the cylinder can be repaired by polishing the inner wall. Use a polishing block consisting of two half cylinders of wood or aluminum faced with abrasive cloth and having a diameter equal to the I.D. of the cylinder. The two halves of the block must be designed so that springs or levers may be used to expand the halves against the walls of the cylinder. The center of the block must be cut away to accommodate the piston tube. The block may be moved up and down by a rod so as to polish the entire inner surface of the cylinder evenly.

Dimensional Inspection.—Inspection should be made to determine the serviceability of the following parts: bronze piston *O*; bronze upper bearing *B*; and bronze lower bearing *M*. Check the diameters of these parts against Table 1, which lists their original dimensions and the allowable service dimensions for each of the assemblies.

Table 1.—Wear Limits of Strut Parts

Strut assembly	Piston *O*		Bearing *B*		Bearing *M*	
	Original O.D.	Service tolerance	Original O.D.	Service tolerance	Original I.D.	Service tolerance
65258–9	2.8425 / 2.8415	2.837	3.623 / 3.621	3.607	3.252 / 3.254	3.269
54250–1	2.8425 / 2.8415	2.837	3.623 / 3.621	3.607	3.252 / 3.254	3.269
65233–4	2.8425 / 2.8415	2.837	3.623 / 3.621	3.607	3.252 / 3.254	3.269
53978–9	2.9355 / 2.9345	2.9300	3.654 / 3.652	3.638	3.252 / 3.254	3.269
53833–4	2.9355 / 2.9345	2.9300	3.654 / 3.652	3.638	3.252 / 3.254	3.269

If inspection shows that the diameter of piston *O* or bearing *B* is less than the service tolerance listed in the table, the part must be replaced. Bearing *M* should also be replaced if the *I.D.* is greater than the listed service tolerance.

Reassembly.—Reassemble the shock struts by reversing the disassembly process, observing the following precautions:

If piston *O* has been replaced, it will usually be found that the lock screw hole *P* will not line up with the hole in piston tube *L*. When this is found, install the piston and piston insert and tighten them securely in place. Put a drill bushing in the piston lock screw hole and ream a hole of 0.187

$+0.001$ in. diameter through the piston tube. Remove the drill bushing, and screw the piston lock screw securely into place.

Before the packing rings, spacer rings, and washers are reassembled, they should be dipped in castor oil. When the bearing nut is being screwed back into position, it should be tightened down so that one man can, *with moderate effort*, move the inner cylinder through its stroke.

Storage.—Struts should not be kept in storage in an inflated condition except for short periods, or when desired for immediate replacement, as the packing deteriorates rapidly when struts are stored while inflated. When struts are to be stored for long periods as spare parts, it is recommended that the inside be coated with a rust preventive and that they be assembled without packing or fluid. It is, of course, very *important that the rust preventive be completely removed* before the strut is fitted with new packing, filled, and reassembled for service. Care must be taken that the substance used in removing the rust preventive is nonacid forming when in contact with the rust preventive.

Landing Gear Mechanisms

Mechanisms for retracting the landing wheels vary widely with the type of plane, weight being a very important factor that must be carefully con-

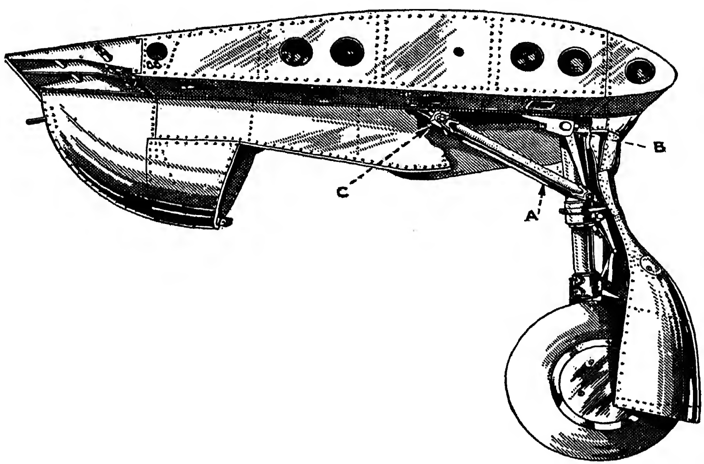


FIG. 6.—Retracting mechanism used on Republic 2-PA plane.

sidered. Outline sketches from *Aviation* show some of these very clearly. The retracting mechanism used on the Republic 2-PA is seen in Fig. 6. Here the wheel and the oleo strut are hinged at B, the strut A connecting the strut with the hydraulic power source at C. A portion of the side housing is cut away to show A and C but it can readily be seen how the shield around the wheel will fit against the housing when the wheel is fully retracted, presenting a streamlined surface while in flight.

The Grumman G-21 A landing gear is seen in Fig. 7. The four struts are hinged at *A*, *B*, *C*, and *D*. Although the angle of the sketch does not make it quite clear, the lifting mechanism at *E* pulls the point *F* at the wheel hub up to point *F'*. Figure 8 shows the tail wheel assembly of the same plane. The wheel is retracted by *A*, which lifts the fork and wheel around

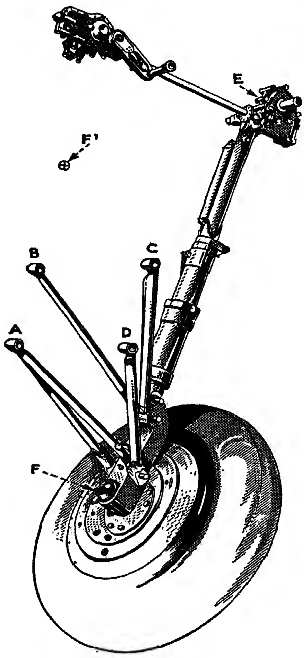


FIG. 7.—Landing gear of Grumman G-21 A plane.

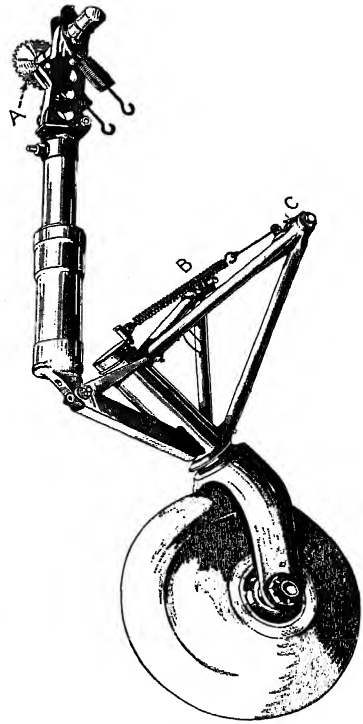


FIG. 8.—Tail wheel strut assembly on Grumman G-21 A plane.

the points *B* and *C*. The springs connected at *B* and *C* return the wheel to normal position after it strikes a bump on the ground.

On the Cessna T-50, the wheel is retracted by an electric motor under the pilot's seat. This motor operates the screw by a chain (Fig. 9). The nut on the screw controls the movement of the wheels. Should the electric motor fail to operate, the screw can be turned by hand.

A nonretractable tail wheel assembly used on the Fairchild 24 is seen in Fig. 10; it is steered by the cables at *A*. The oleo strut at *B* takes the shock of landing on rough ground. A simple tail wheel for trainer use is shown in

Fig. 11. This is on the North American NA-35 trainer. Most of the load is taken at A, with part B taking part of the torque load. It will be noted that this wheel is supported in a half fork.

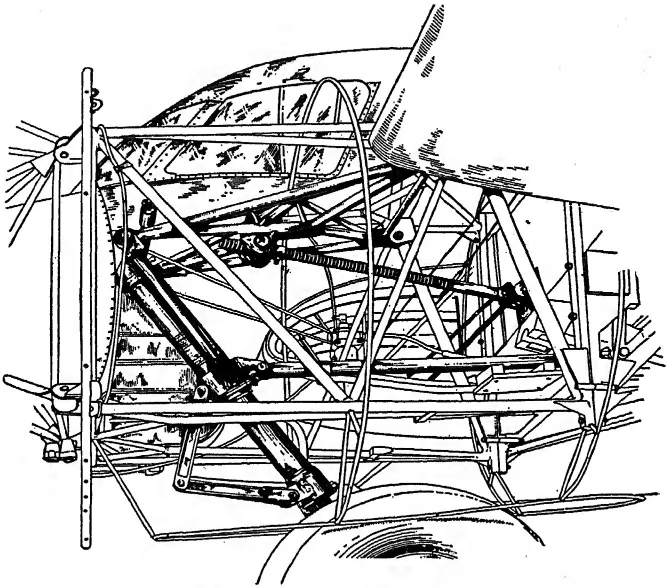


FIG. 9.—Landing gear and retracting mechanism of Cessna T-50.

Firestone Airplane Tires

Demounting.

1. Remove the brake assembly from the wheel.
2. Turn the wheel over, remove the three screws (Fig. 12), and lift off the cover plate.
3. If the wheel and tire assembly has not been touched since it was received from the factory, the bearings and bearing retainers will be wired in place. If this is the case, cut and remove the wire, and remove the bearings and bearing retainers from both sides. If the assembly has been in use, there is no wire to cut, so simply take out the bearings and bearing retainers.
4. Remove the valve inside, allowing the air to escape, and remove the nut from the valve.
5. Remove the five cotter pins and the five castellated nuts from the outboard face of the wheel.
6. Take a short, blunt, tire tool; push one end of it between the tire bead and the flange of the outboard face of the wheel; press down (but *do not*

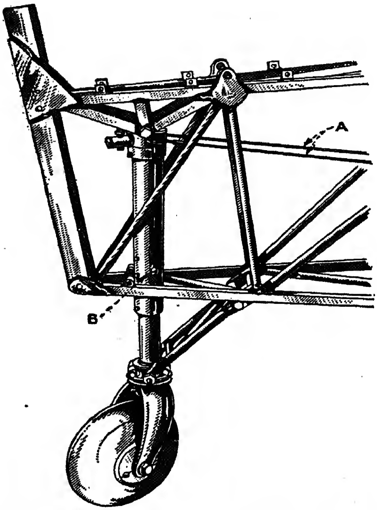


FIG. 10.—A nonretractable but steerable tail wheel used on Fairchild 24 plane.

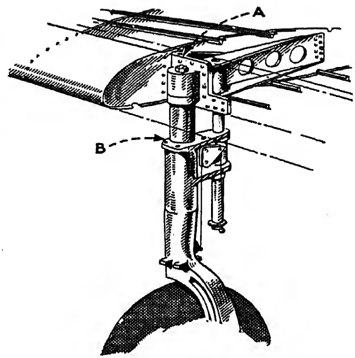


FIG. 11.—A simple tail wheel used on North American NA 35 training plane.

FIG. 12.—First operation in demounting Firestone tires: removing three screws that hold the plate in place.

twist), and repeat this operation at intervals around the tire, to loosen the tire bead away from its seat at the wheel flange (see Fig. 13).

7. With the fingers and thumbs of both hands, remove the outboard part of the wheel from the rest of the assembly, but be sure to leave the bolts in the inboard wheel part (see Fig. 14).

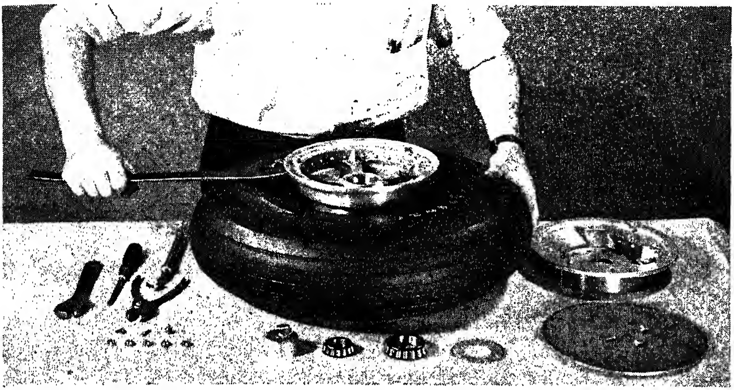


FIG. 13.—Removing the wheel flange.

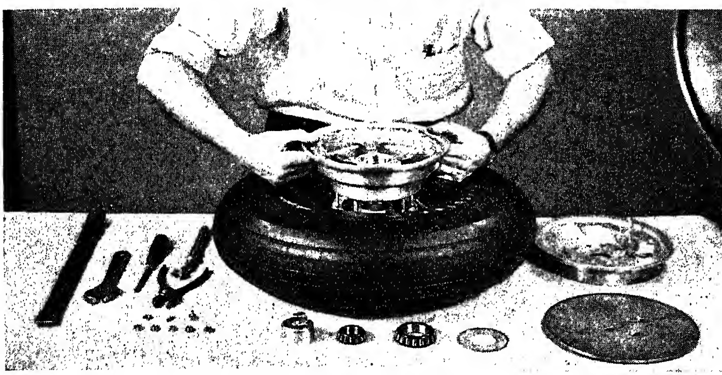


FIG. 14.—Removing the outer part of the wheel from the tire.

8. Turn the tire upside down. Using both hands, press down on the lower side wall to loosen the tire from the bead flange and remove the inboard part of the wheel from the tire (see Fig. 15).

9. Remove the inner tube from the tire.

Mounting.

1. Inspect the tire tread for cuts, nails, glass, etc., and the *inside* of the tire for foreign material such as sand and dirt, as well as for nail holes,

fabric breaks, etc. That is, be sure the tire is in perfect repair and condition, inside and outside, before assembling it with the wheel. Also inspect the tube, just as carefully and, if necessary, inflate it and test under water for leaks.

FIG. 15.—Tire turned over to remove the inboard part of the wheel.

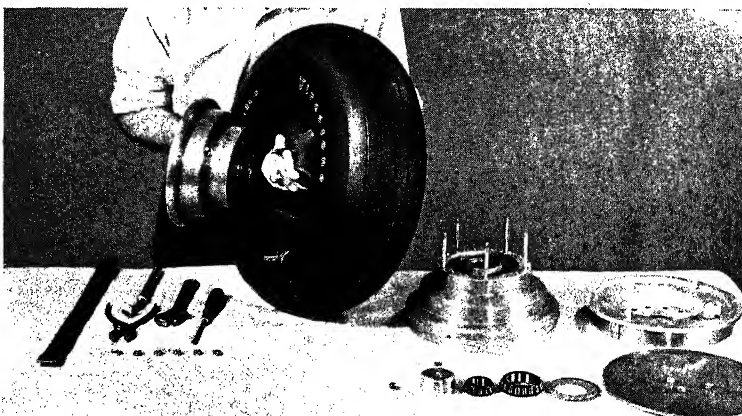


FIG. 16.—First step in mounting the tire on the wheel.

2. Insert the tube, fully deflated, in the tire. Screw the valve inside into the tube. Inflate the tube until the base of the tube is almost fully rounded.

3. Holding the rubber valve stem of the tube in one hand and the outboard part of the wheel in the other, turn this part of the wheel around until the valve stem is opposite the valve hole in the wheel (see Fig. 16).

4. Push the outboard part of the wheel toward the valve stem so that the stem enters the valve hole and emerges on the face of the wheel part. Screw the valve nut on the end of the valve stem (see Fig. 17).

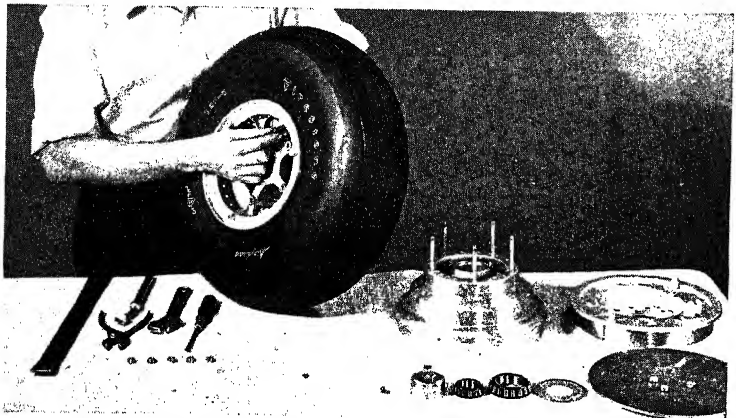


FIG. 17.—Pushing the outboard part of the wheel toward the valve ste:

5. Hold the assembled tire and outboard part of the wheel with one hand, and the inboard part of the wheel with the other hand, as shown in Fig. 18.

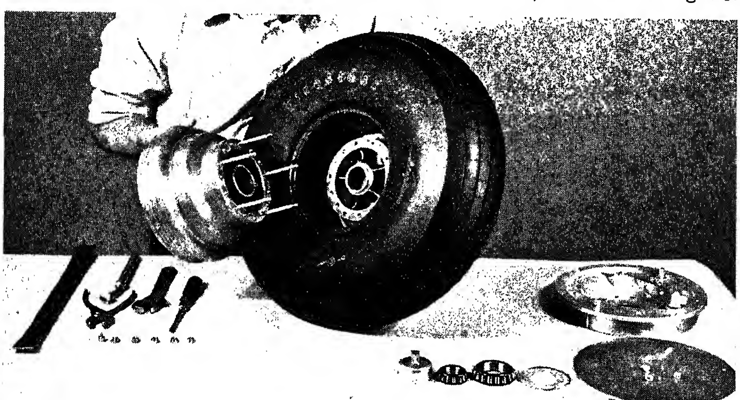


FIG. 18.—Putting the inboard side of the wheel in place.

On the inner face of each of the two parts of the wheel, there are five bolt holes and also a small hole. (The bolts, of course, are already in place in the bolt holes in the inboard part of the wheel.) When the two parts of the

wheel are joined together inside the tire (with the bolts entering the bolt holes in the outboard part of the wheel), the two small holes should come

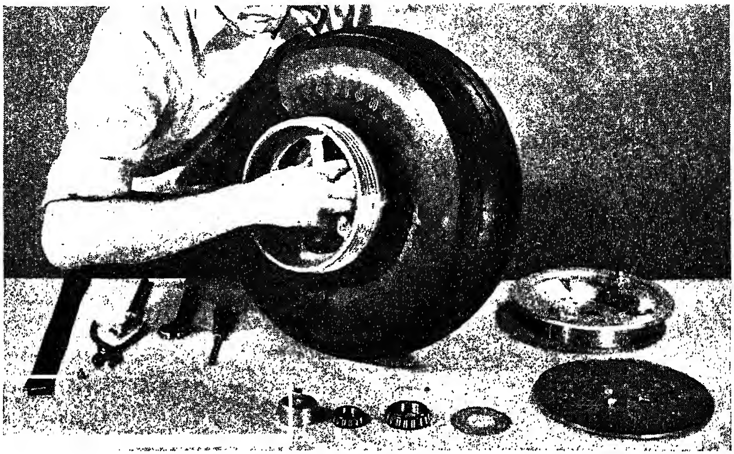


FIG. 19.—Rotating the inboard part until all bolts and bolt holes register

together. So, in Fig. 19, turn the inboard part of the wheel (shown at the left), until not only the bolts and bolt holes register, but also until the small hole in one part of the wheel is opposite the small hole in the other part of the wheel.

FIG. 20.—Press the parts of the wheel together, being certain to maintain the register of the bolts and holes.

6. Press the wheel parts together (see Fig. 20). Be very careful to keep the registering faces of the wheel in contact all the way around. If this is

done properly, the five bolts will protrude exactly the same amount through the outboard part of the wheel. *This is very important.* Serious damage can easily be done to the wheel flanges and bearings if the registering faces are not properly lined up. Also, if there is not enough air in the tube, it is possible to pinch the tube between the wheel parts. So be sure you can feel and hear metallic contact between the wheel parts.

7. Place the nuts on the wheel bolts and turn them down fairly tight with a wrench. Insert the cotter pins in the castellated nuts and spread at the ends.

8. Inflate to required pressure: 25 lb. for 4-ply tires, and 30 lb. for 6-ply tires.

9. Replace the bearings, bearing retainers, cover plate (turn down the three screws), and brake assembly.

Table 2.—Load and Inflation Data for Firestone Standard and Extra-ply High-pressure Landing and Tail-wheel Tires

Size of tire	Inflation, lb. per sq. in.											
	30	35	40	45	50	55	60	65	70	75	80	85
	Load, lb.											
10 × 3	225	260	295	330	365	400*	......	......	600			
14 × 3	275	320	365	410	455	500						
18 × 3	320	370	400	450	500	550						
16 × 4	400	470	540	610	680	600						
20 × 4	450	525	600	657	750	825						
24 × 4	510	595	680	735	850							
26 × 4	...	.....	.....	.....	950							
28 × 4	600	700	800	900	1,000							
30 × 5	950	1,120	1,280	1,440	1,600							
20 × 6	...	.....	.....	.....	.....	.....	.....	.....	.....	......	2,350	
32 × 6	...	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800			
36 × 8	...	2,330	2,670	3,000	3,330	3,670	4,000	4,300	4,600	4,900		
40 × 10	...	.....	3,390	3,810	4,230	4,650	5,080	5,500	5,800	6,050	6,300	
44 × 10	...	.....	.....	4,360	4,850	5,330	5,820	6,500	7,000	7,500	8,000	8,500
54 × 12	...	.....	.....	6,430	7,150	7,850	8,570	9,280	10,000			
58 × 14	...	.....	.....	.....	.....	10,200	11,100	12,100	13,000	14,400	15,700	17,000

* Single underscoring denotes maximum approved loads for standard ply tires: double underscoring denotes maximum approved loads for extra-ply tires.

Tables 2 and 3 give data on weight, air pressures, and other items of both high- and low-pressure tires. Table 2 is for high-pressure tires from 10 × 3 to 58 × 14 in. Table 3 is for low-pressure tires, and Table 4 shows the variations in permissible loads with varying pressures.

Table. 3.—Firestone Low-pressure Landing-wheel Tire Data

Size of tire	No. of plies	Type of tread	Weight, lb.*			Rims		Tire dimensions, in.		Rated max. static load, lb.	Pressure, lb.	Max. available deflection, in.	Approx. collapsing load for full radial deflection, lb.	Max. energy by static loading ft.-lb.	Valve numbers	
			Tire	Regular tube	Puncture-proof tube	Size	Width between flanges in.	Over-all diam.	Section diam.						Rubber	Metal
Standard-ply Landing-wheel Tires																
6.00-6	2	Plain	5.15	1.46	2.99	6.00-6	5	17.51	6.46	600	15	4.28	2,400	394	DD2917	
6.00-6	2	Nonskid	5.95	1.46	2.99	6.00-6	5	17.12	6.43	600	15	4.28	2,400	394	DD2917	
6.00-6	4	Nonskid	6.64	1.46	2.99	6.00-6	5	17.12	6.43	900	20	4.25	2,925	440	DD2917	
6.50-10	4	Plain	8.52	2.44	4.04	6.50-10	4¾	21.73	6.56	1,300	25	4.60	4,600	760	TR-25	
6.50-10	4	Nonskid	8.52	2.44	4.04	6.50-10	4¾	21.73	6.56	1,300	25	4.60	4,600	760	TR-25	
7.50-10	4	Plain	9.85	3.02	5.72	6.50-10	4¾	23.58	7.67	1,600	25	5.25	5,700	1,070	TR-25	
7.50-10	4	Nonskid	9.85	3.02	5.72	6.50-10	4¾	23.58	7.67	1,600	25	5.25	5,700	1,070	TR-25	
8.50-10	4	Plain	11.42	3.48	6.79	8.50-10	6¼	25.36	8.60	1,950	25	6.00	6,700	1,450	TR-25	
8.50-10	4	Nonskid	11.42	3.48	6.79	8.50-10	6¼	25.36	8.60	1,950	25	6.00	6,700	1,450	TR-25	
9.50-12	4	Nonskid	20.03	4.62	.....	9.50-12	7	29.07	9.55	2,600	25	6.12	9,850	2,200	TR-35	
11.00-12	6	Plain	29.92	5.71	11.33	11.00-12	8¼	31.85	11.28	3,700	28	8.00	12,000	3,440	TR-35	
15.00-16	6	Plain	60.59	15.17	34.65	15.00-16	11¼	41.80	14.99	7,000	28	10.25	21,000	8,490	....	TR-94
15.00-16	6	Nonskid	71.30	15.17	34.65	15.00-16	11¼	42.50	15.14	7,000	28	10.25	21,000	8,490	....	TR-94
17.00-16	10	Nonskid	132.19	17.80	35.60	17.00-16	13¼	44.78	17.20	13,500	48	10.90	43,200	18,500	....	TR-93
19.00-23	12	Nonskid	222.9	26.38	57.92	19.00-23	14¾	54.68	19.19	17,000	45	12.00	51,200	19,400	....	TR-98
Extra-ply Landing-wheel Tires																
7.50-10	6	Nonskid	12.75	3.02	5.72	7.50-10	5½	23.65	7.54	2,100	30	4.90	7,200	1,190	TR-25	
8.50-10	6	Plain	15.05	3.48	6.79	8.50-10	6¼	24.79	8.80	2,500	30	5.80	8,700	1,780	TR-25	
8.50-10	6	Nonskid	15.05	3.48	6.79	8.50-10	6¼	24.79	8.80	2,500	30	5.80	8,700	1,780	TR-25	
9.50-12	6	Nonskid	24.62	4.62	9.24	9.50-12	7	29.03	9.56	3,500	35	5.90	11,650	2,500	TR-35	
11.00-12	8	Plain	37.84	5.71	11.33	11.00-12	8¼	31.94	11.38	4,625	35	7.90	14,000	3,900	TR-35	
15.00-16	8	Nonskid	80.96	15.17	34.65	15.00-16	11¼	42.72	15.10	9,500	37	10.00	24,600	9,700	......	TR-93,94†
15.00-16	8	Plain	67.56	15.17	34.65	15.00-16	11¼	42.01	15.22	9,500	37	10.00	24,600	9,700	......	TR-93,94†
15.00-16	10	Plain	78.00	15.17	34.65	15.00-16	11¼	42.08	15.28	10,500	45	9.90	26,700	10,300	......	TR-94†
15.00-16	10	Nonskid	88.00	15.17	34.65	15.00-16	11¼	42.65	15.22	10,500	45	9.90	27,000	10,300	......	TR-94†
19.00-23	14	Nonskid	237.5	26.38	57.92	19.00-23	14¾	54.68	19.19	20,000	55	11.9	57,500	26,800	......	TR-98†
19.00-23	16	Nonskid	252.16	26.38	57.92	19.00-23	14¾	54.95	19.00	22,500	63	11.8	72,000	33,200	......	TR-98†

* All tire and tube weights subject to tolerance of approximately 3 per cent.
† TR-93, 60 deg. bend for dual brake wheel; TR-93, 30 deg. bend for single brake wheel; TR-94, drop-center rims.

Table 4.—Load and Inflation Data

Size of tire	Inflation, lb. per sq. in.																	
	5	8	10	13	15	17	18	20	25	28	30	35	37	43	45	48	55	63
	Load, lb.																	
Standard and Extra-ply Low-pressure Landing-wheel Tires																		
7.00-4	325	...	550	750														
8.00-5	400	...	650	900														
6.00-6	...	...	500	...	700	.....	..	900*										
6.50-10	...	...	600	700	800	.....	..	1,050	1,300	.....	1,700							
7.50-10	...	...	...	...	1,000	.....	..	1,300	1,600	.....	2,100							
8.50-10	...	...	...	...	1,300	.....	..	1,600	1,950	.....	2,500							
9.50-12	...	...	...	...	1,700	.....	..	2,150	2,600	.....	.....	3,500						
11.00-12	...	...	...	...	2,200	.....	..	2,800	.....	3,700	.....	4,625						
15.00-16	...	...	...	...	.....	.....	..	5,200	6,300	7,000	.....	.....	9,500	10,500				
17.00-16	...	...	...	...	.....	.....	..	......	.....	.....	.....	.....	.....	12,500	......	13,500		
19.00-23	...	...	...	...	.....	.....	..	......	.....	.....	.....	.....	.....	......	17,000	......	20,000	22,500
Two-ply Light-service Low-pressure Landing-wheel Tires																		
7.00-4	...	500																
6.00-6	...	300	400	550	600													
8.50-10	...	...	...	...	.....	1,300												
9.50-12	...	...	...	...	1,600													

* Single underscoring denotes maximum approved loads; double underscoring denotes maximum approved loads for extra-ply tires.

Wheel Balancing.—When tire changing or balancing becomes necessary, the following procedure should be used: The tube should be placed in the tire so that the mark (heavy spot) near the inner circumference of the tube is located at the red dot (light spot) on the tire.

The test for balance and the location of the light spot are obtained as follows: Raise the wheel from the ground so that it will revolve freely. Be sure the brakes are not dragging and the bearings are free. Allow the wheel to oscillate until the heavy point rests at the bottom. Mark the light point, which is considered to be diametrically opposite the heavy point. If the wheel should now be excessively out of balance, remove the cover plate on the hub and drill a ¼-in. hole 1½ in. from the edge of the cover and as near as possible to the light spot. Place a ¼-in. bolt in this hole and add washers until balance is obtained.

A more complicated method is the use of Goodrich balance paint on the inside of the tire at the light point. This paint is applied over a large area inside the tire, putting the heaviest coat near the light spot and thinned down at the edges of the painted area. The tire is considered in static balance when the wheel is placed in any position and no angular movement is observed.

AIRPLANE BRAKES

Brakes are important in airplane landing and in taxiing on the field. Hydraulic brakes have come into favor, as they have with automobiles.

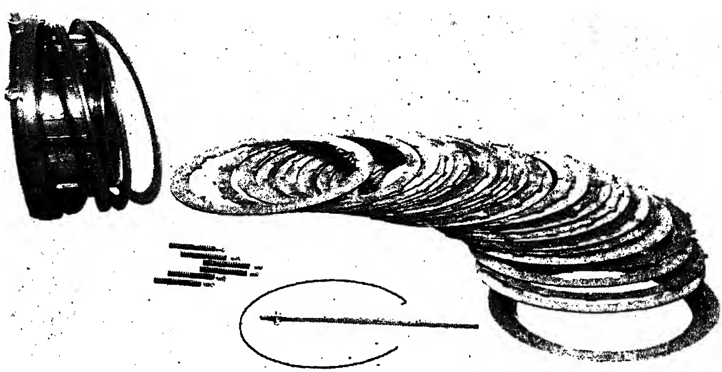


FIG. 21.—Brake rings and carrier for Goodyear brakes.

Although the mechanisms differ, the principles of operation are the same: Hydraulic pressure controls the contact between the braking surfaces whether they are friction plates or bands on brake drums. The Goodyear brake, shown in Fig. 21, uses bronze and steel disks, one set stationary and the other turning with the wheel. When forced together, they provide friction for stopping the plane.

Brake sizes vary widely according to the plane on which they are used; data on intermediate sizes are given in Table 5.

Table 5.—Goodyear Brake Data—Intermediate Sizes

Wheel size	Model	Brake size	Insulator disk	Pressure plate	Rotating disks	Stationary disks	Specified clearance, in.	Actual displacement, cu. in.	Displacement to be provided, cu. in.	Min. I.D. of lines, in.
7.50-10	10HBM	7.6″ × 3	1	..	3	4	0.030	0.59	1.10	¼
7.50-10	....	7.6″ × 4	1	..	4	5	0.030	0.61	1.12	¼
7.50-10	....	7.6″ × 6	1	..	6	7	0.038	0.71	1.16	¼
15.00-16	16HBM	12.7″ × 7 (coil springs)	1	1	7	8	0.042	2.00	3.00	¼
15.00-16*	16HBM	12.7″ × 7 (bow springs)	1	..	7	8	0.042	2.00	3.00	¼
15.00-16	16HBM	12.7″ × 9	1	..	9	10	0.054	2.52	3.78	5/16
15.00-16	16HBMS	12.7″ × 13	1	..	13	14	0.078	3.18	4.75	5/16
15.00-16	HD16HBA or M	12.7″ × 9	1	..	9	10	0.054	2.52	3.78	5/16
15.00-16	HD16HBMS	12.7″ × 14	1	..	14	15	0.112	4.60	6.90	⅜
15.00-16	HD16HBMS	12.7″H × 12	1	..	12	13	0.096	3.40	5.10	⅜
39 × 13.50-16	16HBMS	12.7″ × 13	1	..	13	14	0.078	3.18	4.75	5/16
17.00-16	....	12.7″H × 16	1	..	16	17	0.128	5.15	7.75	⅜
17.00-20† (dual)	....	2 × 12.7″H × 13	1	..	13	14	0.104	4.39	6.60	⅜
19.00-23	23HB	12.7″ × 18	1	1	18	19	0.108	4.53	6.80	5/16
19.00-23	HD23HB	12.7″ × 19	1	1	19	20	0.114	4.64	6.95	5/16
19.00-23	HD23HBS	12.7″ × 25	1	..	25	26	0.150	5.04	7.50	⅜

* Two spacers next to adjustment nut.
† Figures given are for each brake unit.

Goodyear Hydraulic Disk Brakes and Wheels (Size 7.50-10 Mounting on 6.50-10 Axle, and for Either 6.50-10, 7.50-10, or 8.50-10 Tires.)—These are extremely simple, practically foolproof, powerful, smooth, quiet, and long wearing. The mechanism is nothing more or less than a multiple-disk metal-to-metal clutch especially designed and built to function as an airplane brake. Bronze disks are keyed to rotate with the wheel. Alternating steel disks, which are nonrotating, are keyed to the brake anchor bracket. The parts are seen in Fig. 21. These disks are pressed together by means of a piston actuated by a fluid line connected directly to the brake pedal. Braking power depends on the pressure applied to the pedal.

A master cylinder provides the proper amount of pressure for the brake system. Proper linkage is provided so this master cylinder builds up the required fluid line pressure proportionate to foot pedal pressure and travel. This master cylinder is, in reality, a pump, kept supplied with fluid by gravity from a supply tank mounted usually just ahead of the fire wall. When the brake pedal is applied, the piston in this master cylinder creates the desired amount of pressure in the fluid line below the master cylinder. This pressure is directly transmitted to the wheel piston which then presses the disks together.

When the plane is ready for delivery, the hydraulic brake system has been properly *adjusted and bled* so that there is no air in the entire system. If there were, this *air* would be compressed when the brake pedal is applied and no movement of the brake piston would result. As delivered, the braking system should be good for a great number of normal landings, and it should not be necessary to add more brake fluid to the supply tank, rebleed the system, or replace any parts.

If any dirt gets into the system, there is a possibility that small particles might destroy the complete seal of either the front or the rear master cylinder

seal, or possibly the brake piston seal. This would cause loss of fluid and possible entrance of air into the line. This condition can usually be detected due to the presence of fluid at these points. Should this occur, it would be necessary to flush the entire system, clean the two rubber seals in the master cylinder, or the brake piston seal if the leak is at the brake, by washing them in industrial or denatured alcohol. *Never use wood alcohol, gasoline, or oil on the rubber parts.*

Bleeding the System.—It will then be necessary to bleed, to eliminate all air from the system. The first step is to see that the supply tank is full of fluid. The recommended brake fluids are Univis No. 40, Stanavo No. 9, and Mobiloil SS mineral oil. These can be obtained from any Standard Oil or Socony-Vacuum Oil Co. bulk station or branch, or from practically any air-line service hangar.

Special synthetic piston seals are required for both the brakes and the master cylinders when mineral oil is used in the system. Whenever replacement seals are ordered, be sure that *synthetic* seals are specified. Regular rubber seals, as previously used with Lockheed fluid, will not function satisfactorily in mineral oil. *Synthetic* seals can be identified by the marking "17027" or "P59" on the inside. Regular rubber seals contain the marking "4821" on the inside. The master cylinder seal rings contain no marking but rings of synthetic compound have one or two upraised dots on the inside periphery.

Bleeding with Air Pressure.—There should be a valve stem in the top of the supply tank. If so, attach an ordinary hand pump to this valve stem, remove the cap screw from the bleeder plug in the brake, and insert in its place a standard bleeder hose (obtainable from any garage). Place the free end of the hose in a clean glass receptacle, back off the bleeder plug, and immediately start pumping on the hand pump connected to the reserve tank. This will force the fluid through the system rapidly and pick up any air in the system.

Normally, after about ¼ pt. has come through into the receptacle, no more bubbles will appear and the system is then bled. The bleeder plug should then be tightened and the cap screw with washer replaced. Be sure to replace the valve cap on the reserve tank valve. Otherwise, fluid might be lost in flight or dirt might get into the supply tank. Also make sure that the air vent in the valve cap is clear.

Bleeding without Air Pressure.—If no valve stem is provided in the supply tank cover, bleed as follows:

See that the supply tank is full of fluid. Remove the bleeder plug cap screw and washer from the bleeder plug in the brake and insert in its place a standard bleeder hose. Place the free end of the hose in a clean glass receptacle and back off the bleeder plug, which will allow fluid to flow by gravity and fill up the system. This will require several minutes.

Push down the brake pedal rapidly. While fluid is flowing from the bleeder hose into the receptacle, shut off the bleeder plug and allow the pedal to return to the full off position slowly. This draws new fluid into the system from the supply tank. Again back off the bleeder plug, push down the pedal rapidly, and, while fluid is flowing from the hose, shut off the bleeder plug. Allow the pedal to return to full off position slowly.

Repeat this operation until no more air bubbles come from the bleeder hose. Then shut off the bleeder plug, remove the bleeder hose, and replace the bleeder plug cap screw and washer. Check the supply tank to make sure that it is still at least half full of fluid. Replace supply tank cover;

otherwise, fluid might be lost in flight or dirt might get into the tank. Also make sure the supply tank cover air vent is clear.

Dirt in the system might possibly clog the compensating port in the master cylinder. If this should happen, the pressure or volume on that particular brake could not be compensated and the brake would pump up through several strokes of the foot pedal (or due to expansion from heat developed through use of the brake) and remain locked. Locked brakes are impossible with a system which is clean and properly installed; but should this happen, remove the master cylinder, clean all parts of the cylinder, and be sure that the small compensating port *ahead* of the piston is not fouled.

Naturally, the rotating bronze disks in the brake wear, and greater foot-pedal travel results. When the foot-pedal travel has become excessive, remove the wheel from the brake unit and take up on the brake disk adjustment and lock nut. Screw the disk retaining and adjustment nut up tight, then back off until a 0.030-in. feeler gage can be inserted between the disks. (This means for the entire set—not for each disk.) Proper clearance can usually be obtained by tightening up the adjusting nut as tightly as possible with the hands and backing off approximately one-half turn. Brakes with six bronze and seven steel disks should have 0.040 in. clearance between disks.

Back off the disk retaining and adjustment nut to the next lock position (eight positions are provided) and install the lock screw. If the disks are sufficiently worn, they should be replaced by removing the wheel from the brake unit, removing the disk adjustment and lock nut, sliding the disks off the brake assembly, and installing new ones. Care should be taken to see that a steel disk is installed next to the asbestos insulating disk; also that a steek disk goes on last, just before the adjustment nut.

When remounting the wheel on the brake unit, the keys extending from the bronze disks should all be lined up with a straightedge, and the parking level applied to hold them in that position. This will permit easy mounting of the wheel on the brake assembly. If the keys are not held in position by the parking lever, the rotating bronze disks may move, and it will then be hard to center them on the keys in the wheel drive ring.

Goodyear Master Cylinders.—As control of an airplane on the ground requires separate or divided wheel control, a master cylinder is used for each wheel (Fig. 22). These master cylinders are designed for aircraft use and made of special lightweight alloys. They are known as barrel type, compensating master cylinders and three sizes are available: 1 in., 1½ in., and 2 in. I.D.

This type of master cylinder constantly maintains the correct volume of fluid under either extreme heat or cold conditions by compensating for the change in volume due to expansion or contraction. It also automatically replaces any fluid lost through leakage and practically ensures air from entering the system due to any leaks. The hydraulic pressure necessary to operate the brake is developed in the master cylinder by movement of the piston 6, usually by means of the brake pedal.

Univis No. 40, Stanavo No. 9, or Mobiloil SS brake fluid is fed by gravity from the supply tank to the cylinder via the inlet port 22 and compensating port 21, and fills the master cylinder, the connecting line, and on down to the brake cylinder.

Application of the brake pedal causes the piston rod 4 to push the piston 6 forward. A slight forward movement blocks the compensating port 21 and the building up of pressure begins. When the brake pedal is released

and returns to "off" position, the spring 9 returns the piston 6 and front piston seal 10 to the full "off" position, and again clears the compensating port 21.

Fluid in the line and brake cylinder is returned to the master cylinder by the pressure of the brake return springs, on the brake piston. Any pressure or excess volume of fluid is relieved by the compensating port and passes back to the supply tank. This ensures against the possibility of dragging or locked brakes being caused by the master cylinder.

If, owing to leakage, any fluid is lost back of or to the left of the front piston seal 10, this is automatically replaced by gravity from the supply tank.

Any fluid lost in front of or to the right of the front piston seal 10 by leaks in the connections, line, or at the brake, is automatically replaced by fluid

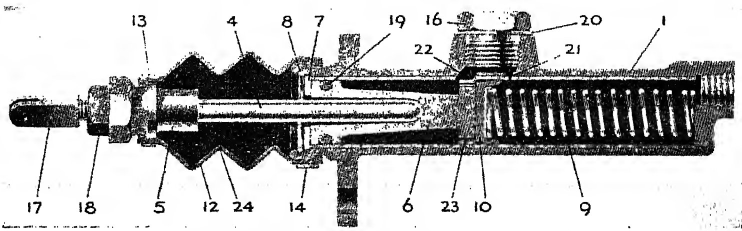


Fig. 22.—Master cylinder for Goodyear airplane brake.

1. Master cylinder casting (machined) with insert sleeve
4. Master cylinder piston rod
5. Master cylinder piston rod coupling
6. Master cylinder piston
7. Piston return stop
8. Piston return stop lock wire
9. Spring with seat
10. Front piston seal or cup (rubber)
12. Rubber boot
13. Rubber bootstrap, small.
14. Rubber bootstrap, large
16. Inlet connector fitting—¾ in. O.D. S.A.E. 16 thread × ¼ in. I.D. pipe thread
17.* Master cylinder piston rod clevis
18. Master cylinder piston rod clevis check nut
19. Rear piston seal (rubber)
20. Inlet connector gasket—1¹⁄₁₆ in. O.D. × ¾ in. I.D. × ¹⁄₃₂ in. thick, aluminum
21. Compensating port
22. Gravity inlet port
23. Piston head ports
24. Boot air vent

* Clevis-type piston rod terminal furnished with 1-in. master cylinder only. Sizes 1½ and 2 in. furnished with eye-bolt terminal.

passing through slots 23 in the piston head and around the lip of front piston seal 10 when the piston makes the return stroke to the full "off" position. Seal 10 functions as a seal only during the forward stroke. Consequently, if there is fluid in the supply tank, the master cylinder, connecting line, and brake cylinder are always full of fluid and ready for operation.

Only Goodyear master cylinders should be used with Goodyear hydraulic disk brakes as they have been specially designed with regard to the volume of fluid and the pressure and length of stroke required for that particular braking unit. The airplane manufacturer has designed the brake linkage according to those conditions.

The rear piston seal 19 seals the rear end of the cylinder at all times and prevents leakage of fluid. The flexible rubber boot 12 is only a dust protector.

Adjustment.—The length of the combined clevis 17 and piston rod 4 is the only adjustment available or necessary on the master cylinder. The coupling 5 is made integral with the piston rod 4 in the assembly and provides only the hexagonal nut for adjustment and a female thread into which the

clevis is screwed. Any reference to piston rod 4 means "piston rod with coupling attached."

To adjust the length, loosen lock nut 18. To increase the length of the combined piston rod and clevis, turn coupling 5 clockwise if stationed behind master cylinder, that is, at the end opposite the outlet; to decrease the length of the combined piston rod and clevis, turn coupling 5 counterclockwise. With the clevis attached to the linkage provided by the airplane manufacturer, the piston rod length should be so adjusted as to permit a slight amount of play when the piston rod is shaken.

When this condition exists, the piston 6 must, owing to the tension of spring 9, be in full "off" position and back against the piston return stop 7. This ensures clearance for the compensating port 21 and consequent proper functioning of the master cylinder.

No change or adjustment of the piston rod length should ever be required if the brakes function properly when the ship is delivered by the manufacturer.

Maintenance Hints.—The following hints will be found helpful for Goodyear Hydraulic Disk Brakes, Size 7.50-10.

Excessive Pedal Travel.—The probable causes are as follows:

a. Normal wear of bronze disks
b. Improper adjustment or clearance between disks
c. Leak in the system
d. Air in the system
e. Improper adjustment of length of master cylinder piston rod
f. Improper brake pedal setting or linkage
g. Lack of fluid in supply tank
h. Vent in supply tank stopped up
i. Improper bleeding—air mixed with fluid

The remedies are as follows:

a. As the disks wear and become thinner, the brake piston must travel farther. This results in greater fluid displacement and consequently calls for greater pedal travel.

Remove the wheel from the brake unit. Remove the retaining nut lock spring from the brake unit. Turn the retaining and adjustment nut up tight. Then turn it back until 0.030-in. clearance is available on brakes with three or four bronze disks, or 0.040-in. clearance on brakes with six bronze disks. This can be determined by forcing a feeler gage between the disks. (This means for the entire set—not for each disk.) Replace the retaining nut lock screw and lock in the next lock point. When disks are so thin that further adjustment is impossible or when conditions call for renewal, replace them with a new set.

b. The adjustment for standard 7.50-10 brakes with three or four bronze disks calls for 0.030-in. clearance between disks. (This means for entire unit—not for each disk.) This can be measured with a feeler gage. The adjustment for the HD. 7.50-10 brake with six bronze disks calls for 0.040-in. clearance between disks.

c. If the pedal will gradually go clear on under pressure, there is a fluid leak in the system. Trace it out. If the rubber piston seal is worn or shrunk, replace it with a new *synthetic* seal No. P59. If old-type coil tension and compression springs are installed in the seal, replace them with the latest leaf type expander spring.

d. A springy, rubbery action of the pedal indicates air in the system. An excessive amount of air will permit the pedal to go full on under normal pressure. In either case the system should be bled.

e. If the master cylinder piston rod was assembled and installed so that it was shorter than proper, excessive pedal travel would result. Refer to Adjustment (page 644) for the proper setting.

f. This could not occur if the brakes functioned properly when the airplane was delivered. It could only occur because of tearing down of the linkage, as during overhaul, and not reassembling properly. Correct to the original condition.

g. Air will enter the system if the supply tank runs dry. Supply tank should be checked at regular intervals and be kept at least one-half full.

h. If the vent in the supply tank becomes stopped, it is possible to create a vacuum in the tank so that fluid would not feed into the system by gravity. The lack of fluid in the system might permit excessive or full-pedal travel without resultant brake operation.

If the supply tank vent cap has a rubber gasket inside, this rubber may swell from the action of mineral oil, thus plugging the vent hole. To correct this condition, remove the gasket from the vent cap, as it serves no particular purpose.

Check the vent in the supply tank and see that it permits passage of air.

i. If too much air pressure is used when bleeding the system or the system is bled several times in a short period of time, the fluid may become full of small air bubbles. In either case, wait until air accumulates in large bubbles so it can be eliminated by bleeding, or drain and refill the system with new fluid.

Dragging Brakes.—The probable causes are as follows:

a. Improper adjustment or clearance between disks
b. Improper adjustment of length of master cylinder piston rod
c. Dirt in system
d. Binding of brake piston or dust shield
e. Use of improper fluid
f. Weak or broken brake piston return springs
g. Weak or broken master cylinder piston return spring
h. Dished or warped bronze or steel disks
i. Mechanical pedal linkage frozen
j. Parking brake

The remedies are as follows:

a. If disks are adjusted to provide more clearance than recommended, excess pedal travel will result; if they are adjusted to provide less clearance than recommended, expansion due to heat resulting from operation may cause dragging or even locked brakes. See remedy *a* (page 645) for the proper adjustment.

b. If the master cylinder piston rod is adjusted so as to be longer than proper, the compensating port would be covered and the system could not compensate. This might cause dragging brakes. Dragging brakes from this cause may develop sufficient heat to expand the fluid to a point where the brakes would lock even though the brake pedal were in the full off position. If allowed to cool, the brake will function again but the cause should be determined and corrected or the same condition would develop again.

If the brake locks out on the field, open the bleeder plug at the wheel. This will release the pressure and the ship can be taxied from the field. However, the cause should be determined and corrected before operating further as otherwise the same condition would occur again. See Adjustment (page 644) for the proper setting or adjustment.

c. Dragging or locked brakes may be due to dirt in the system, particularly in the supply tank. Dirt might clog the compensating port in the

master cylinder and dragging or locked brakes would result. Dirt in the system may also get under the rubber seals in the master cylinder or under the brake piston seal and cause leaks, as described in (*c*) (page 645). If dirt is found in the system, remove both master cylinders and dismantle the brake assemblies. Then flush the supply tank and lines thoroughly with mineral oil fluid. Fluid used for flushing should be thrown away at once or strained carefully to remove any foreign particles.

Dismantle the master cylinders and clean the rubber seals in alcohol and clean all metal parts. Then reassemble and install as before.

Clean the brake piston seal in denatured alcohol and clean the brake cylinder and piston. Then reassemble as before.

Fill the supply tank and system with new, clean Univis No. 40, Stanavo No. 9, or Mobiloil SS mineral oil fluid and bleed.

d. Dust and dirt mixing with brake fluid at the brake piston may become gummy and may cause sticking of the brake piston or even cause air leaks. The parts should be removed and thoroughly cleaned in alcohol; then reinstall as before.

e. Improper fluid may not operate properly under severe heat or cold conditions; it may destroy the rubber seals in the master cylinders or at the brake piston or cause swelling of the rubber seals with resultant closing of the compensating port. In such a case, replace them with new seals, flush the system thoroughly with alcohol, and fill and rebleed with mineral oil fluid. *Synthetic* seals are required with this fluid; they have markings "17027" or "P59" on the inside. Rubber seals having any other marking should be replaced.

f. If the brake piston return springs are broken or weak, the brake piston would not return to full "off" position or would move slower than proper. Consequently the returning fluid would move sluggishly and the usual feel of the brake would be lacking. This might also cause dragging or locked brakes. Install new springs.

g. If the master cylinder spring is weak or broken, the master cylinder piston will not move back against the piston stop and the compensating port would not be cleared. Remove and replace with new springs.

h. Dished or warped disks seldom occur. However, if disks are discovered to be in this condition, remove them and place them on a flat plate and tap until they return to flat condition; then reinstall. If this is impossible to correct or if the disks have become too badly worn from operating in this condition, they should be replaced with new ones. Dished or warped disks would change the clearance or adjustment, and dragging brakes might result.

i. If the mechanical linkage is frozen up, it might be impossible for the master cylinder to operate properly even though the brake pedal is in full off position. Check out and free up the point of trouble.

j. Parking devices improperly installed or adjusted may cause dragging brakes owing to the fact that the master cylinder piston is not permitted to return against the piston stop even though the foot pedal is in full "off" position. Check for this possibility. The parking device should be adjusted or interference cleared so that the master cylinder can operate as described under Adjustments (page 644).

Volatilization of Brake Fluid.—Temporary loss of brakes may be usually attributed to volatilization of the brake fluid. The most satisfactory hydraulic fluids available until recently permitted vaporizing at too low a temperature to permit satisfactory brake operation under adverse conditions.

Progress and requirements have led to research and development of other fluids with the idea of providing better features and additional efficiency. The original recommendations for brake fluid to be used in connection with hydraulic brakes were Lockheed No. 5 or No. 21, but these recommendations have recently been changed to Univis No. 40, Stanavo No. 9, and Mobiloil SS mineral oil which have a vaporizing point about three times higher than the Lockheed fluids.

Wherever possible, approved mineral oil should be used in the hydraulic brake system. Synthetic seals must be used in the brakes and master cylinders when mineral oil brake fluid is used. Whenever a change-over is made from Lockheed fluid to the mineral oil, it is imperative that such synthetic seals be used. In the case of the small 1-in. master cylinder seal ring where it is impossible to place any marking, the synthetic seal ring can be identified by one or two small upraised dots on the inside periphery.

It has been found practically impossible to volatilize mineral oil brake fluid under the most severe brake service; any trouble that has been experienced along these lines can definitely be corrected by changing over to mineral oil.

Leaking Brakes.—A survey of the hydraulic brake problems and troubles listed during the last five years indicates that a large percentage of the difficulty was caused from leakage of the brake fluid past the piston seal in the brake. Up to Sept. 1, 1938, the method of preventing leakage past the brake piston seal was a coil tension and compression spring assembled under the lips of the rubber seal. Although this system proved fairly satisfactory, it involved a certain amount of difficulty in properly installing the springs and getting the seal so equipped properly mounted in the piston cavity. There were some cases where leakage was encountered even though the springs were properly assembled.

Goodyear now has available a new type expander spring which is very easy to apply to the piston seal and which will correct the leakage problems sometimes encountered with the previous type. All 7.50-10 hydraulic brakes furnished by Goodyear since Sept. 1, 1938, have been equipped with these new expander springs; they will be furnished in the future on all orders for replacement of the old coil tension and compression springs.

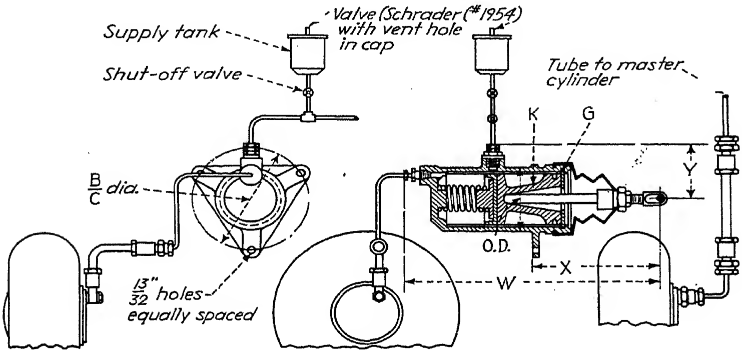
In installing the new expander springs there are several points that must be particularly watched to ensure proper functioning in the piston seal. This new expander spring has narrow slits on one side and wider slots on the other; it should be installed lips up in the seal and with the wide slots toward the inside and the narrow slits toward the outside, making certain that each segment seats under the lips of the rubber piston seal.

The mounting of the expander spring can be facilitated if the seal is lubricated with some brake fluid thereby permitting the spring to adjust itself easily. Then thoroughly clean the brake fluid cavity, cover it with brake fluid, and insert the seal and spring assembly lips inward, being careful to feed the seal into the cavity progressively so as not to cut the lips or force the spring from under the lips.

The outer lip of the seal should first be worked into the outer piston cavity wall to a depth of about ¼ in. or until the inner lip meets the offset ledge of the inner piston cavity wall. Then a blunt screw driver or similar tool may be inserted between the rubber seal and the offset ledge of the anchor bracket and the inner lip of the seal forced into the inner cavity wall by following the tool around the circle with the index finger on top of the seal.

Particular care should be taken to work the seal in slowly and not to cock it excessively, which might cause the expander spring to jump out of place from beneath the lips of the seal and result in leakage. If properly assembled and installed, this new expander spring should definitely eliminate any leaks in the brake assembly.

Minor Brake Problems.—A few isolated cases have been reported of lack of proper brake torque on these 7.50-10 hydraulic brakes before the airplane has received much service or after new replacement bronze disks have been



Size	1	1½	2
Piston area sq.in.	0.78	1.77	3.14
Max. piston stroke	1.43	1.43	1.43
Max. displace. cu. in.	1.11	2.53	4.49
O.D.	1 5/16	2 1/4	2 3/4
B.C. dia.	2 3/4	3 1/4	3 3/4
Complete wt. lbs.	0.75	1.60	2.05
W	9 1/2	11	11
X	4 1/2	5 5/8	5 5/8
Y	1 7/16	1 13/16	2 1/16

FIG. 23.—Installation diagram of Goodyear brakes.

installed. This lack of brake torque has been attributed to a graphite residue which in some cases is left on the laminated bronze rotating disks. This reduces the coefficient of friction until the disks have been worn sufficiently to remove this graphite residue. It is advantageous to sandblast or to clean with sandpaper all the bronze disks in any brakes that do not give full brake torque.

Where there is insufficient return spring pressure, this condition can be eliminated by installing a set of double-leaf type return springs. The 7.50-10 hydraulic brakes manufactured before Jan. 1, 1937, were equipped

with single-leaf type return springs which do not exert proper pressure after they have been in service for some time. The latest type piston return springs are somewhat wider than the previous type and it is necessary to file the spring slots in the anchor bracket to permit their installation.

General Information.—The 7.50-10 hydraulic brakes were originally designed to accommodate only four bronze and five steel disks in the brake stack. New style brakes are equipped with three, four, five, or six bronze disks and four, five, six, or seven steel disks. Those with three bronze and four steel disks may be used on all Waco ships of under 3,750 lb. Brakes with four bronze and five steel disks are recommended for planes between 3,750 and 4,250 lb. Ships over 4,250 lb. should use brakes with five or six bronze disks and five, six, or seven steel disks.

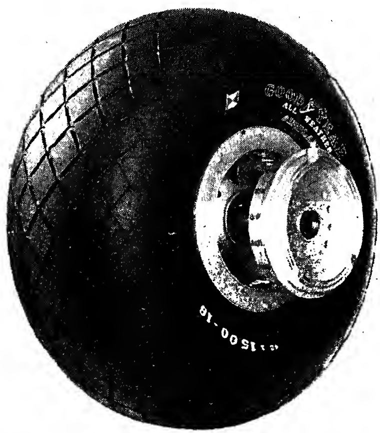


Fig. 24.—Goodyear 15.00-16-in. tire and brake.

On new style 7.50-10 brakes manufactured after Dec. 1, 1939, any number of bronze disks from three to six may be installed. Brakes manufactured prior to that date will accommodate a maximum of four bronze disks. New style brakes can be used only in connection with new style wheels; old style brakes may be used with either old or new style wheels.

In Fig. 23 are shown two methods of installing the master cylinder. One method shows the hose at the wheel, the other at the upper end of the axle strut. Figure 24 shows a wheel with 15.00-16-in. tires, tubes, brakes, and wheel used on the Lockheed Lodestar planes of the commercial lines, and also on the Hudson bombers used by the Royal Air Force.

FLOATS FOR SEA PLANES

Unpacking and Installation.—Edo floats are packed in light crates for domestic shipment; for export, they are shipped in heavy planked boxes. The tops of the export boxes are marked and should always be removed first. The domestic crates are not marked in this way but they should always be opened by first removing the planks next to the bottom. After these planks are removed the float should be lifted straight up. This method subjects the crates to the least damage so that they can be used again if required. In no case should boxes or crates be opened by removing the sides, since the keels of the floats are blocked in place; this would prevent their coming out through the side without damage.

The struts, wires, and attaching fittings of a complete float installation are packed in a separate box for domestic shipment and in a part of the main box for export. No particular precautions are needed in unpacking these parts except that the contents should be checked with the packing list immedi-

ately upon removal. Before starting any installation work, the drawings should be carefully examined and thoroughly understood. All parts for U.S. licensed seaplanes are made to drawings approved by the C.A.A. and, if the drawings and instructions are properly interpreted, the parts should fit.

Hoisting the Plane.—Where a combined airport and seaplane base is not available the floats can often be installed at an airport, the wings removed, and the ship trucked to the water. In other cases the ship can be towed to a beach on its wheels and the floats installed. A crane or a tripod can be used for hoisting but be sure plenty of reserve strength and height are provided as the plane stands higher on floats than on wheels. In the event that hoisting lugs are not provided on the ship or engine, it is usually best to attach the rope of the hoist to the engine mount of the airplane, and the weight of the entire ship should be carefully considered as far as the strength of the hoisting equipment is concerned.

Another hoist or some other suitable support should be arranged under the tail which will bring the fuselage approximately level, when the plane is hoisted into position, and great care must be exercised as the wheels first clear to prevent any sudden movement due to initial inclination of the hoist. A provision should also be made to block under the wing tips to prevent the machine from tipping. Accurate leveling is not required, but locating the machine in an approximately level position and blocking it securely will greatly facilitate the work. On light planes it is often easier to block up the forward end (motor mount) and also the tail rather than to use a hoist.

Assembling the Float Gear.—Before attempting to install the floats, it is important that the assembly drawing supplied with each float gear be carefully studied, as well as the following general instructions which apply to all installations. Before attaching any parts, however, great care must be taken to see that grease (such as Rust Veto) is generously applied to all surfaces. Rust Veto A-7 manufactured by the Houghton Co. is suitable for this purpose since it adheres well and is also a good lubricant. This precaution will expedite the work and is of the greatest value as a corrosion preventive.

The floats should first be laid on the floor or on planks correctly placed, right and left hand, approximately the correct distance apart. If the installation includes spreader tubes and cross brace wires they should be installed. On present production floats the right or left can be determined by looking for an "R" or "L" on the name plate, following the manufacturers' serial number. On older models they can be distinguished right and left by fittings which attach to the ends of the spreader tubes, and are found only on the inner side, next to the fuselage. Others can be distinguished by offset fittings on the deck. In this case, floats on which fittings are found to be one side of the center line should be set with that side nearest the fuselage of the plane.

Most present production float models have streamline sleeves built into the sides of the float, the top halves of which should first be removed in order to insert the spreader tubes. The spreaders are positioned by a fitting which is screwed through the deck and serves at the same time as the socket for the ball end of the struts, after which the upper half of the sleeve is bolted securely in place. Special instructions for assembling are sent with each float gear. *In all types of sleeve spreader tube installations the joints should be carefully and generously packed with dolphinite or some equivalent sealing compound, or the joints may become a likely source of leaks and possible corrosion.* The light plane spreaders have bolts on the top and bottom which are passed into castings and through into the float. It should be especially

noticed that the rim on the half of the ball joint fitting which comes with the float should be brought down so that it lies evenly with the deck.

After the spreader tubes have been installed, the horizontal cross brace wires should be put in place and trammed so that the floats are in proper alignment. The wires should be drawn snug, but it is important to be sure that none of the brace wires are ever overtightened. The points of contact where they cross should be protected with friction tape. The main fuselage attachment struts should next be fastened to the floats, with careful attention to the drawing and the tags on the struts. The only exception to this rule is in the case of ball-and-socket type installations where the struts are first fastened to the fuselage and later attached to the sockets on the deck of the floats. At this stage of the work all attachment bolts should be left loose so that the struts can be easily moved as required.

Installing Floats on the Plane.—The landing gear can now be removed from the fuselage and the float attachment fittings should be taken off the upper ends of the struts and installed on the fuselage. In some cases variations are encountered in the fuselage fittings of the airplane which makes it necessary to file the float attaching fittings until they fit. The complete float installation should now be moved under the plane and raised until the ends of the struts slide over the fittings which are already attached to the fuselage, and all bolts inserted. It is much better as a rule to raise the floats than to lower the plane. All additional bracing, such as V struts or cross brace wires, should now be installed and trammed for alignment after which all nuts should be drawn-tight and cottered. All brace wires should be snug but *excess tightening should be carefully avoided*, since it puts an additional and dangerous load on the struts, and is very likely to induce bowing and the possibility of failure.

It is very important that the nuts on all bolts at the ends of the struts are drawn tight so that the swivel fittings on the floats or on the fuselage are clamped securely between the strut ends, and so that there will be absolutely no looseness or play in these joints. When the installation is completed the machine may be lowered onto suitable beaching gear (see page 657) or on planks that have been placed beneath the keels, with the tail of the floats supported by blocking so as to prevent any possibility of tipping over backward.

Connecting the Water Rudders.—Floats are usually shipped with the water rudder attached, and it is only necessary to connect up the controls. In most cases, all fittings necessary for this purpose will be furnished with the floats while a drawing showing their location in the plane will be found in the float gear instruction envelope. In some cases, however, it may be necessary for the customer to devise the control connections to fit his plane. This can be done by using the universal type pulleys and fittings which would be furnished for the purpose. The following description of the general principles and common methods of rudder control connections is offered as a guide for such cases. In the case of a first installation, connecting up the water rudders often takes as much time as the installation of the floats. Where the job must be done on a beach, much of the cabin work can, therefore, be done advantageously beforehand in a hangar where better facilities are available.

The water rudders are actuated by cables that connect their horns with the rudder control system of the plane. Generally the cables from the outer horns can be connected to the rudder pedals in the same manner as the air rudder wires, or connected to the air rudder wires themselves by means of

clamps. In this case the inner horns are hooked up to an interconnecting cable that runs between the floats. Sometimes, however, it may be found necessary to run the rudder cables forward from the rudder pedals instead of aft, in which case the wires will have to be crossed or connected to the inner horns of the water rudders in order to secure the proper motion. It is of course important to be sure that air and water rudders work in unison.

The general arrangement of the controls is seen in Fig. 25. In connecting the cables, it is usually convenient to fasten the turnbuckles directly to the water rudder horns where they can easily be adjusted. From the rudder horns, the cables are ordinarily passed through the nest of pulleys A which will be found on the inboard deck clamp, a short distance from the stern. After passing this nest of pulleys, *the rudder interconnecting cable* passes

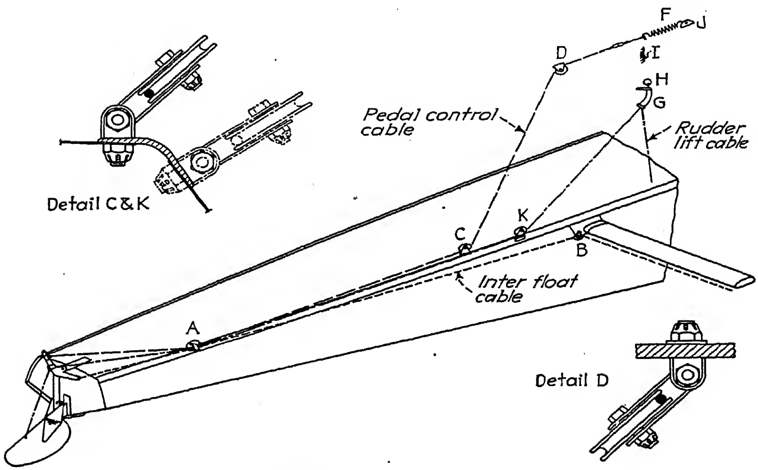


Fig. 25.—Arrangement of controls on the Edo floats.

through a pulley B which will be found mounted on the rear spreader tube fitting, and thence along the trailing edge of the spreader tube to similar connections on the opposite float. The *control cable* passes through pulley C on the float, pulley D in the fuselage, and is fastened to the air rudder control. The coil spring F is inserted between the water rudder and air rudder control in order to prevent any possibility of jamming the air controls in the event that the water rudder system should freeze up or jam. This spring should be located in front of pulley D in the fuselage, or in fact as near the connection to the air rudder as possible. In some instances, there is no room in the fuselage and it is necessary to locate the spring between pulleys C and D, but *in no case should the spring be located aft of pulley C on the deck of the floats.*

The connection of the water rudder control cable to the airplane rudder controls is accomplished most easily by attaching it to a clamp J on the air rudder cable in Fig. 25. Sometimes this is not possible either because

of lack of room, or because of too short a travel of the air rudder cable. In such instances, it may be necessary to attach the cable directly to the rudder pedals, making such necessary fittings as may be required out of strip steel. When the air rudder cable travel is unusually short, it often becomes advisable to fit extensions to the rudder pedals, and fasten the water rudder cable to them. Such extensions are usually cut from ⅛-in. steel plate and bolted to the side of the pedal, extending far enough below or above them to satisfactorily increase the throw. It has been found by experience that *a total rudder cable travel of* 6 *in.* is desirable to secure the best results.

The use of brake pedals for the water rudder controls often appears to offer an attractive solution to the problem. Experience has shown, however, that the *amount of throw is always insufficient.*

Pulley D is usually suspended from the floor of cabin planes, or from the rear seat of open cockpit planes. Its location is chosen so that the cables will have a free lead and will not interfere with other parts of the plane. In plan view, it is determined by the location of the rudder cables. The long clevis pin in which the pulley swivels must be made parallel to the cable leading forward to the pedals or air rudder connections. The pulley will then line up automatically with the after section of the cable, regardless of its direction. Pulley C is located on the deck coaming of the float so as to give the best direction for the cable leading to pulley D. It is desirable to have pulley C slightly aft of pulley D so as to make the cable change its direction by less than 90 deg. to provide for easier control.

Testing the Rudder Throw.—The rudders will not give satisfactory results unless they swing through an arc of at least 45 deg. from either side of neutral when tested on land. This throw is necessary to compensate for the inherent slack in the system and to ensure sufficient movement under operating conditions in the water. The throw can be increased by shortening the water rudder horns. It is much better to try to lengthen the movement in the fuselage such as by moving the point of attachment further up or down on the rudder pedal. Although the rudders are balanced, they, nevertheless, require a reasonable force to move. If there is an unusually large amount of spring or slack in the system, the rudder movement may be very small under operating conditions even if it has the proper throw when tested on land. This seriously reduces the effectiveness of the water rudders. In order to test for excessive slack, hold the rudder pedals hard over and then try and push the rudder straight by hand. It should yield only if strong pressure is applied.

Connecting the Rudder Lifts.—It is necessary to provide the water rudders with a cable that will enable the pilot to retract them before take-off, or while handling the seaplane under certain conditions on the water. The design of the rudder blades is such that they will rise up or retract automatically when running at high speed, due to the friction of the water, as well as in the event that objects in the water are stuck. This automatic retracting, however, should only be considered as a safety precaution, and the rudders should not be abused by permitting them to bang up and down during take-offs and landings or while taxiing on the step in rough water. It is desirable to retract the rudders when backing in on a beach or in sailing backwards in a high wind, since in this condition the water rudders oppose the air rudder.

The retracting cable is fastened to the side of the water rudder blade by means of a thimble, freely swiveling over a bolt and spacer which is mounted on the blade. From this bolt, the cable passes through a fairlead on top of

the water rudder post; through either a pulley or a fairlead in the pulley nest A; and through another pulley K on side of the deck coaming. From K the cables from both floats enter the fuselage through a guide tube G and are fastened to a common ring H. The length of the cable is adjusted so as to let ring H lie on the floor at the mouth of guide tube G when the rudders are lowered. To lift the rudders, ring H is pulled up and fastened to a hook I located in any convenient position. In open planes, it is usually fastened to one of the side tubes of the fuselage. In cabin planes, it should, if possible, be fastened to the lower edge of instrument board, or else to the floor at a proper distance aft of guide tube G. In very large ships where the retracting forces are excessive, a special hand winch is generally required; in the case of ships equipped with hand parking brakes the retracting cables can conveniently be attached to a clip secured to the brake lever.

The guide tube G is usually made with a flange welded to its upper end and fastened to the floor with machine screws. It is best bent aft to line up with the cables in side elevation, and flared to take care of the cables running to the right and left hand floats. It is often further improved by fitting a Bakelite fairlead instead of flaring it at the lower end.

Precautions to Ensure Maximum Performance.—If the motor or propeller of a seaplane is not 100 per cent efficient *the take-off performance will be much more seriously affected than it would be with a land plane.* The reason for this is because the wheel landing gear of a land plane, during take-off, offers no appreciable ground resistance at any speed so that the total thrust of the propeller is available for acceleration. In the case of a water take-off, however, a large proportion of the power is required to overcome the water resistance of the hull or floats, and for this reason only a small reserve is left available for acceleration, in many instances not more than 10 per cent. This shows that although a 10 per cent reduction in the thrust of a land plane will have but little effect on the take-off time, this same reduction might eliminate all of the reserve thrust of the comparable seaplane, and could easily make a take-off impossible under any conditions. It is therefore extremely important to check carefully both the engine and propeller, when putting a ship on floats.

Checking Engine Power.—One of the most common mistakes in checking the power of an engine is to assume that, if it turns up the proper amount on the ground, its full power is being delivered. This, of course, is true if the same fixed pitch propeller is constantly used; but where an adjustable propeller or an untested fixed pitch propeller is substituted, the only sure check on power is to install a propeller which an identical motor in good condition was known to have turned a certain r.p.m. In many instances of poor take-off the motor was "revving" up, but it was not delivering its power.

Another equally important factor in take-off is the propeller. Since most seaplanes are slightly slower than the same ship would be on wheels (because of the drag of the floats), the identical propeller will not give the full throttle r.p.m. on a seaplane as on a land plane. This, of course, means that the full power of the motor is not being delivered as a seaplane, and in all probability the maximum possible speed as a seaplane is not being reached.

Checking the Propeller.—In such cases the pitch of the propeller should be reduced until the *maximum allowable r.p.m.* is secured, which under existing regulations is defined as the *rated r.p.m. plus 5 per cent.* To test this the ship should be flown full throttle at sea level for 3 or 4 miles to be sure the maximum is attained. In the case of adjustable propellers the required change

in setting is easily accomplished. With forged dural propellers the blades can generally be twisted sufficiently (on a propeller stand) to get the desired result; in the case of wood, a different propeller will have to be secured. The change, however, is in all cases well worth making, for in doing so the r.p.m. and consequently the power available during the take-off period are correspondingly increased, which in most cases *guarantees a marked improvement in take-off efficiency.*

In addition to r.p.m. the diameter of the propeller should also be considered, because when the drag of a ship is increased (by the floats) a larger propeller is generally necessary in order to obtain the maximum high speed efficiency. Of much greater importance, however, is the fact that the resulting increase in propeller disk area *will add tremendously to the thrust available at take-off speeds.* Incidentally, the improvement in take-off due to larger diameters will be most noticeable in high-speed ships which require high-pitch propellers, and which find difficulty in getting onto the step of the float. For these reasons substituting longer metal blades or ordering a specially designed wooden propeller is often well worth considering. In the case of the light planes two wooden propellers of the same design will sometimes give r.p.m. variations of as much as 15 per cent. Being sure that you have a good propeller is worth much effort.

Overloads.—Still another important factor on the subject of water take-offs is the gross weight of the plane, for even a small increase in displacement may have a marked effect on the drag of the floats at their critical speeds. Ships with large tanks which have been placarded against full cabin loads are frequent offenders, since it is a simple matter for the mechanic to fill up the ship with gas without the pilot's being aware of it. In the same way leaking floats that have not been repaired and pumped dry can add tremendous unseen weight to the plane. Overloads, like poor engines and propellers, make the whole ship feel sluggish both in getting onto the step and into the air, and are a frequent cause for mistaken criticism of the float gear. If in doubt, it is not a bad idea to get the ship on some scales and find out what load it is actually being asked to carry.

Using Flaps.—Seaplanes equipped with flaps can almost always improve their take-off by their judicious use, in spite of the fact that the flaps may not noticeably help the take-off as a land plane. The reason for this is that the flaps increase the lift, which means that the ship does not need to reach so high a speed on the water in order to fly. It is also true that the flaps cause drag as well as lift, but their drag is invariably less than the water drag of the floats at the maximum speed at take-off.

The lift of the flaps does not help much in getting onto the step. Their drag is often a hindrance. For this reason, it is usually advisable not to lower the flaps until take-off speed is almost reached. The degree to which they should be lowered will vary with the type of plane; the best method of using them can be arrived at only by test. It should further be noted, as a matter of caution, that when flap take-offs are accomplished, great care should be taken to *pick up comfortable flying speed before raising them gradually to normal position.* A sudden loss of their lift might abruptly drop the ship back into the water.

Abuse of Floats.—A little care on the part of the pilot will greatly lessen the amount of maintenance that is necessary. For example, there is a *critical speed* at which the maximum amount of spray gets into the propeller. Taxi below or above this speed. Be on the lookout for large waves created principally by boats. They are always worse than larger waves made by

the wind. On rough days sheltered water can often be found a short distance from where you would normally land. Don't come up to docks or runways too fast.

Launching and Hauling Out.—Edo floats are designed and built with strong, heavy keels, forward of the step, perfectly capable of carrying the entire weight of the ship on land, *providing the load on them is reasonably distributed.* The simplest and often the safest way to haul out or launch a seaplane is to slide it gently on the keels of its floats on a wooden planked surface which has been wet down or greased to make it slippery. Even occasional planks, laid crossways (like railroad ties) on a sandy beach have often been successfully used in an emergency. It is important, however, to see that the floats are slid *only in a straight line—either forward or backward*—and at right angles to any cracks. Sliding them sideways or *twisting them around should never be permitted* since the keels are almost certain to catch and become damaged, particularly at the skeg aft of the step. Furthermore, great care should be taken to see that the keels always bear on at least several feet of even surface, so that the load is *never concentrated at a single point, particularly between bulkheads.* This warning is especially applicable when blocking up under the floats *aft of the step,* since no reinforced keel is provided in that section of the bottom.

Beaching on concrete will rapidly wear out the keels; even sand on a wooden runway should be avoided as much as possible. In the same way, beaching on pebbles, which puts sharply concentrated loads all over the bottom (instead of an even load entirely on the keel), is bound to dent the plating.

Beaching Gear.—Where various types of beaching gear are employed, these precautions should always be followed in protecting the bottoms. If the axle holes in the floats are used it is important to *see that no twisting strains are imposed on the spreader tubes and attaching struts.* Four wheels of equal diameter (one on each side of each float) with a short axle passing through each float, will evenly distribute the loads, but in cases where two wheels and a long, through axle is employed, it is important to make sure the axle is stiff enough to hold its shape and not pass on the strain to the spreader tubes instead. Wheels with pneumatic tires are recommended wherever possible.

General Float Maintenance. *Winter Storage.*—Many floats are taken off during the winter. In case they have been used in salt water, they should be washed very thoroughly with a hose both inside and out to remove all salt deposits. They should be stored in a dry, well-ventilated room, and placed upside down on boxes or horses, clear of the floor. It is important to set the hand hole covers off center, so as to allow ample ventilation and prevent internal sweating. Naturally, all bare steel parts should be thoroughly protected with grease.

Inspection for Damage.—Due to the simple construction of Edo floats, it is practically impossible to damage them without being able to detect the damage by examination from the outside. A very hard landing has been known occasionally to wrinkle the covering on the side or deck sheets near the strut attachment points, but a slight deformation of this nature can often be ignored. It should be watched, however, and, if it becomes worse, it should be repaired as described later. Bad landings, but more particularly a series of very hard landings are, however, much more apt to weaken the lower portions of the bulkheads and injure the bottom, particularly in the straight portion just forward of the step. A very slight concavity in a deformed bottom is rather hard to see and if any doubt exists it is recom-

mended that a straightedge be laid fore and aft along the stringers to check it. Cracks in the bulkheads can generally be detected by a flashlight.

If either the stringers or the bulkheads have been forced in *more than* $\frac{1}{4}$ *in.*, it means that the bottom has been strained and every landing will make things worse, until finally serious cracks in the bulkheads or bottom will undoubtedly develop. Deformations in the planing area of the bottom are also likely to affect the action of the float at high speed and may cause a serious tendency to nose over. In most cases a deformation caused by a rock is less serious than equal amount of deformation caused by bad landings. Both should be attended to as described on page 661. Floats with deformed bottoms or even cracked bulkheads can be flown for some time but the damage will grow progressively worse and the ultimate repair bill will be proportionally higher and actual collapse in landing may occur.

Corrosion.—Under the present Edo manufacturing methods, corrosion has been entirely eliminated as a serious problem except in tropical salt water. Under normal conditions such corrosion of the floats as may take place is most likely to be found around the rivets and can be detected by small white spots protruding through the paint. Salt deposits or young barnacles have a similar appearance, but the latter are on the outside of the paint and will wipe off leaving the paint intact; whereas corrosion is formed under the paint and causes it to bubble up. The metal underneath will be slightly pitted and discolored. Surface corrosion of this nature, which does not penetrate the sheet and destroy its structure, is not serious but should not be permanently neglected.

Where the corroded area is small, the deposit should be carefully scrubbed or wire brushed and new primer and paint applied to the spot. Indiscriminate use of wire brush or emery cloth can be very harmful, however, since it removes the protective layer of pure aluminum on Alclad as well as the anodic film. If corrosion is general, all the paint should be removed and the entire float refinished.

Painting.—To refinish a float properly the old paint should first be removed; for this purpose a good grade of commercial paint remover is recommended. Any corroded spots should then be lightly wire brushed until the discolored material is bright again. The float should next be washed with a cleaning solution such as Valentine's No. 1044 solvent or Pierce & Stevens cleaner, and then with vinegar, followed by fresh water. *The use of vinegar is important*, to neutralize the solvent and ensure a good bond for the paint. It is important not to allow the cleaning solution to soak into the seams since it would dissolve the seam compound and might tend to cause leaks. Care also should be taken not to touch them with greasy hands after cleaning since it would interfere with proper adhesion of the primer. One thin coat of zinc chromate primer (such as Berry Bros. P-27) is then sprayed on. It should be followed by two spray coats of pigmented lacquer.

In preparing the lacquer, it is suggested that 2 lb. of extra fine aluminum powder be thoroughly mixed into 2 qt. of lacquer thinner. After stirring thoroughly, add to the mixture 1 gal. of exterior clear lacquer (such as Berryloid #507). With this method the flakes of aluminum powder form a protecting scale which prevent water from penetrating. Where this plan cannot be followed, a good grade of salt water resisting paint, enamel, or pigmented varnish may be used.

It is recommended that the inside of the floats be sprayed or painted with aluminized Bakelite varnish. In preparing the varnish 1 lb. of extra fine

aluminum powder should be thoroughly mixed into 1 qt. of "paint and varnish makers" naphtha. After stirring thoroughly, add the mixture to 1 gal. of standard Bakelite varnish. If this solution is to be sprayed, it can be reduced to proper consistency by adding additional naphtha. It is recommended that the solution be used in as heavy a state as possible. This is a good protection against corrosion and tends to seal minor leaks. In hot climates and salt water operations Bitumastic solution is sometimes used on the outside of the bottom instead of the standard finish.

Inspection for Leaks.—Water tests should be made after every overhaul as well as for the general detection of leaks, and the ship must be hauled out for the purpose. Before filling with water, however, it is absolutely essential to brace the floats properly, since they may otherwise be severely strained by the weight of the water and leaks, not occurring in normal use, may appear. Properly fitted forms, located under bulkheads and spaced about 4 ft. apart with additional supports for the keel in between, are suggested as the best arrangement. If this is impractical, see that the keel forward of the step is *flat on the floor*, get several supports under the keel at the bow and stern, and block up at a number of points along the chine as well.

To test the floats, fill alternate compartments with water and, after noting any leaks between bulkheads, fill all compartments and inspect for leaks outside. Unless the floats are very well braced, it is advisable, however, to fill only part of the compartments at any one time. All compartments should be filled to the top. Leaks are best marked with an indelible pencil. The water can be siphoned out with a hose.

Stopping Minor Leaks.—Slight seepage of water from one compartment to another is ordinarily permissible unless the floats are to be left out at moorings, unattended for long periods. But an appreciable trickle of water between bulkheads (such as a cupful in 10 min.) should be stopped, as should any leak whatever through the outside skin. As a rule an application of Bakelite seam compound or Dolphinite will cure all minor seam leaks, but it is advisable first to remove the excess of old seam filler and then apply new. *Both are supplied in the standard Edo repair kit.*

In certain cases it will be necessary to tighten up a few rivets. This is done by holding a heavy piece of iron against the inside of the rivet and hammering lightly on the outside of the rivet. If the leak is a stubborn one it is generally advisable to remove a number of rivets as described on page 660, clean out the seam, put in new packing with Bakelite seam compound or Dolphinite, and put in new rivets.

A frequent source of leakage is found in the hand hole covers, particularly if the plane is carelessly nosed up on a steep beach so that the rear deck is under water. To prevent seepage, the vent hole drilled in the covers to prevent the floats from blowing up during a rapid climb should be kept plugged with heavy grease. The rubber gasket will also get old and worn in time and requires replacement, and care should be taken to see that sand does not prevent its proper fit. Sometimes the metal cover itself does not fit snugly down onto the deck. This can be tested by removing the gasket and screwing down the cover to see that even contact is made. If it does not fit tightly, either the thread of the screw is at fault or else the flange in the deck is too wide and should be filed away so as to enlarge the hole. *Never allow hand hole cover knobs to be tightened with wrenches.*

General Repairs.—Riveted aluminum alloy structures of this type are easy to maintain and repair. By reading the instructions and examining the

fastenings in the floats, a mechanic and helper should learn in a few hours' time how to take out and put in rivets for a minor patch. Practice on scrap pieces of metal, however, before starting on the actual float.

Equipment.—The tools required are some drills, tin shears, a hack saw, file, hammer, wooden mallet, small cold chisel, rivet set, and a bucking bar. A rivet set is a punch with a concave end of the size which one wishes for the head of the rivet. The bucking bar is an iron or steel bar weighing from 1 to 5 lb. which is pushed up against the head of the rivet; as a rule the heavier the bucking bar, the better the job. The part of the bar pressing against the rivet can be either smooth or slightly roughened so as to get a better grip on the rivet.

The material required is a piece of Alclad sheet, some rivets, Parker Kalon bind head screws, and machine screws (cadmium plated, if possible) as well as some cotton cloth and seam tape, Dolphinite, and Bakelite seam compound, all of which are supplied in the standard Edo repair kit. The proper rivet to use is A17 ST as supplied by the Aluminum Co. of America or Edo, which does not require heat treating. Ordinary 17 ST duralumin rivets can be headed cold without heat-treatment, in an emergency, but they are harder to rivet and if overworked will become brittle and crack. It is very important not to use any brass or copper rivets or screws, as these will cause very rapid corrosion of the Alclad.

Taking Out Rivets.—Rivets can be removed by knocking their heads off by a side blow with a small cold chisel. *A single smart blow* with a hammer will knock the head off whereas a series of gentle blows will tend to tear the sheet. As a wide cold chisel cuts into the sheet, it is best to grind down a center punch or rivet set so that the end is at a slight angle and has a flat elliptical face of about 3/8 in. This tool, if used as a cold chisel, is less likely to cut into the sheet. It is also a good plan for a helper to buck the rivet from the inside, especially if the rivet is in thin sheeting. The head having been knocked off, the shank of the rivet can be knocked out with a punch. If the float has been painted several times, it is best first to remove the paint around the rivet head so the work can be seen better.

Before attempting to knock off the head of a rivet, it is well to drill some distance into the head with a drill somewhat smaller than the shank. This weakens the head and it can then more easily be removed. Center-punch the center of the rivet head to start the drill. With a little practice, however, especially if an electric drill is available, it is very easy to weaken the head and then knock it off with a cold chisel without in any way damaging the metal or enlarging the rivet hole.

Driving Rivets.—If the rivets have been removed carefully, the same sized rivet can be replaced in the holes. The shank of the rivet should project out a distance equal to about 1½ or 2 times its diameter. It may be necessary to use long rivets and cut off the shank to the required length. The rivet is usually put in and bucked from the inside so that the head is formed on the outside, and it is well to daub the hole with Bakelite seam compound to prevent leakage and corrosion. Until experience has been gained, the rivet should not be set too tight. A loose rivet can be tightened but too much hammering may injure the sheets, causing dents and tending to expand the metal so that it bulges between rivets.

There are two essentials in driving rivets properly. The bucking bar must be held tightly against the rivet. Check this by trying to push the rivet in before starting to put a head on it. In the second place, the sheets of metal which are being riveted must be drawn tightly together before riveting is

started. This can be done by the free use of machine screws in preliminary clamping of the sheets together.

If many rivets are to be put in, a special draw set can be used to advantage. This is a rod with a hole drilled in one end to a size $\frac{1}{32}$ in. larger than the shank of the rivet. The hole is shallow enough to expand the head of the rivet at the same time that it draws the metal together. After the rivet has been placed in the hole and bucked, a few blows are given with this tool before driving it. If the rivet is properly driven and the sheets drawn together, a water-tight joint is assured. If the sheets are not drawn together, the shank of the rivet will expand between the sheets and although the rivets may look all right from the outside, water will leak in between the sheets.

It is advisable to use a rivet set to put the head on the shank of the rivet. It should be held parallel with the shank or else a defective head will be formed. Eight or nine blows with a medium weight hammer on the set should be sufficient to form a good head. There are a few awkward places in the float where it is very difficult to insert a rivet from the inside. In these cases, insert a wire through the hole in the float from the outside. This wire can be fastened to the rivet by filing a point on the rivet and drilling a hole through the narrow part. The point of the rivet is then drawn through the hole by pulling on the wire. Do not unfasten the wire until the rivet is properly "bucked" from the inside.

Where compressed air from 80 to 150 lb. pressure is available, a type U Boyer compressed-air scaling hammer will drive rivets in about half the time required by hand. In this case, the rivet is pushed into the hole from the outside and the hammering is done against the head of the rivet. The pushing up of the bucking bar against the shank of the rivet forms a head on the inside. This type of hammer requires care in handling and is not recommended unless extensive rebuilding work is to be accomplished.

Straightening Dents.—If a float has been slightly dented, it can be hammered back into shape by placing a flat piece of wood against the deformed part and hammering on the projecting material with a wooden mallet. A stick of wood pounded with a hammer will often reach spots where a mallet cannot be used. Where dents have produced very sharp bends in the metal, they can still be hammered out but in this case it is advisable to reenforce them by putting on a patch (see page 662), even though the flattening out of the metal has not caused any apparent cracks.

As previously noted, the portion of the bottom just forward of the step plays a most important part in the take-off characteristics of the floats. If it is even slightly dented or deformed, it may make itself felt by a tendency to "porpoise" or nose over in high-speed travel on the water. For this reason, even small dents must be corrected in this area. With the exception of this area, however, dents had probably best be left alone, since hammering changes the molecular structure of the metal, weakening it and making it more subject to corrosion; in the absence of heat-treating facilities as little should be done as possible.

Patching.—Welding any part of the floats *must be absolutely prohibited* since it is extremely difficult to accomplish. It would destroy the strength of the heat-treated metal as well as the Alclad protective film. For this reason where the metal has been cracked or punctured or requires reinforcing, a patch is always applied and the operation should be performed with care.

Never try to patch over a dented or torn piece of metal, until it has been hammered back into shape. Before making a patch, the paint should be removed and the region of the damage carefully examined for cracks or tears

radiating from the edges; these should all be cut away. After the extent of the damage has been determined, the edges should be trimmed out with shears or a hack saw, so as to form a symmetrically shaped hole with sound metal all the way round, and carefully smoothed down with a file (see Fig. 26).

The next step is to cut out a patch large enough to overlap the edges of the hole by approximately ⅝ in. all the way round, using Alclad sheet, one or two gages heavier than the damaged material. A row of rivet holes should then be laid out and center punched on the patch, ¼ in. from the edges of the patch with a spacing ⅜ in. on centers. Unless the material is over 0.040 in. thick rivets of ⅛ in. diameter should be used; for heavier gages $\frac{5}{32}$-in. rivets should be used.

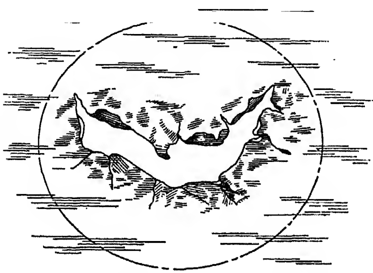


Fig. 26.—All torn or bent metal should be cut away before applying a patch.

To apply the patch, three or more holes should first be drilled through both the patch and the piece under repair and machine screws put in so as to hold the patch in place, until the drilling and riveting are completed (Fig. 27). Be sure to have the patch set firmly against the float before drilling or it may get out of alignment when riveting is started. The patch should always be applied from the outside, and drilling will be greatly facilitated if a block of wood is held against the metal from the inside. To ensure water tightness and prevent corrosion, cotton cloth or seam tape, thoroughly soaked in Bakelite seam compound, should be placed between the patch and metal under repair. This same procedure should be followed in making up any other water-tight joints or seams in the repair of the floats. Although the cotton is omitted in nonwater-tight joints, such as auxiliary framing between bulkheads, the surfaces should be painted with seam compound before riveting in place.

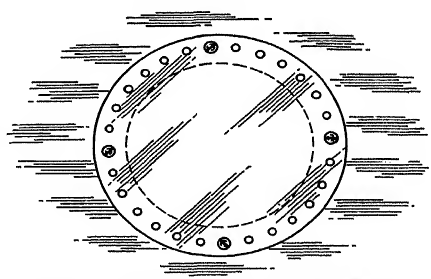


Fig. 27.—Use three or four holding screws until other rivets are in place.

Patching with Screws.—Where rivets are not available or where, because of lack of time or facilities, it is impractical to use them, steel machine screws may be used for temporary repairs. Parker Kalon screws can also be used. They are set with a screw driver and they have the advantage of not requiring any attention from the inside of the float. This is of great value in emerging use and where difficult spots must be reached. With these screws it is very important, however, to *use exactly the right size drill* before setting them in place. The correct size will also generally be found marked on the box of screws. They should be long enough to protrude through the sheets

with one thread showing. Both machine and Parker-Kalon screws are, of course, only temporary and should be replaced with rivets at the first opportunity.

Removing Decks.—Removing the decks gives good space to work in and often means quicker and better results in case of a general overhaul or major repairs. It is done by knocking out the rivets and, where the damage area is localized, it may save time to remove only the section of deck between two bulkheads. This is done by cutting the deck sheet with a drill and hack saw. To make the cut strong and water tight when replacing it, an extra strip about 1½ in. wide is lapped over the joint. In the shop two men can generally remove the decks of an average size pair of floats in a morning and put them back in a day. The same holes are used in putting decks back. The rivets fastening the deck to the stringers and bulkheads are put in and bucked from the inside by reaching through the hand hole covers, and riveted in the usual manner.

Replacing Sheets.—When a large area is damaged, it makes a better job to remove a section of the sheets instead of trying to put in a very large patch. Such a replacement should extend at least the length between two bulkheads, and the joints should be made at the bulkheads, rather than between them. In splicing on a new sheet, a double row of rivets should be used on the bottom; a single row will answer in the side. In most cases it is easier to put both rows on the flanged side of the bulkhead. Although it takes more time, it makes a better job if a reinforcing strip is put on the inside of the bulkhead flange. It is very important that the old holes in the original metal match exactly with the holes drilled in the replacement sheet or patch. Otherwise, if new holes are drilled between the old holes, it will so weaken the sheet as to affect its strength seriously.

To ensure matching of the holes, either drill the patch from the inside, using the old holes as a guide, or else mark the patch very carefully with a pencil so that the center of the mark is exactly over the center of the hole. In thin sheets, in cases where a drill will not reach a hole from the inside, it is possible to push a sharp instrument, such as an ice pick or center-punch hard up against the inside of the sheet. By hammering lightly on the outside of the sheet with a mallet a slight projection results which can serve to locate the hole.

Repairs of Buckling—Internal Failures.—If the side sheets have been slightly wrinkled by very hard landings, they can be bumped out by bracing the outside of the float at the bulkheads and hammering from the inside with a board hit by a wooden mallet. The stringers can generally be straightened in the same manner and it is then advisable to rivet some extra ones on the inside to keep the damage from spreading. If the float is buckled to a point where there is a sag of more than ¼ in. in the deck line, or the bottom stringers in the flat portion forward of the step, or if the side sheet wrinkles are very sharp, it will probably be necessary to remove the deck to make a thorough inspection and replace those stringers that are bent. Hammering out irregularities requires both skill and experience as the metal must usually be "shrunk" which is a difficult process. The average amateur often makes a wrinkle worse by trying to straighten it. An internal or external reinforcement which keeps the wrinkle from spreading and restores the structural strength is a safer job; in many cases it looks as well.

There is also a possibility that the sheets will have been strained so that they may crack when straightened. If this is the case, it is generally advisable to remove the damaged ones and splice on a new section.

In the case of a float that has been seriously buckled, the bulkheads should also be carefully examined for buckling or cracks particularly at the bottom, near the flange. If the buckle is not bad, it can be hammered out and a reinforcing plate fastened on. This should usually be flanged over and fastened on the opposite side from the existing flange. If the buckling is so bad that the bulkhead has cracked, it is advisable to saw out the bottom half

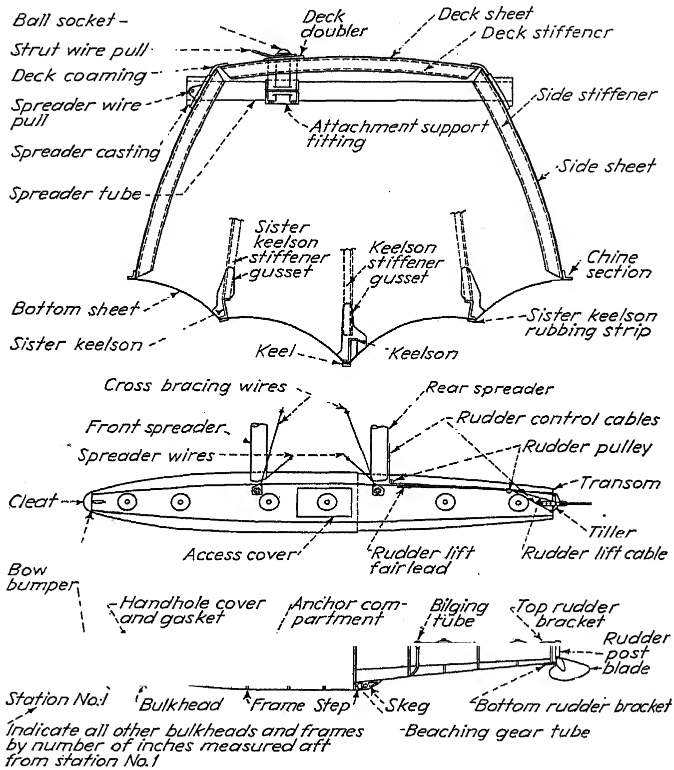


FIG. 28.—A section and outline of floats with parts named.

and rivet on a new portion. Bulkheads of production floats are generally stamped at the factory to standard sizes and it is usually easier and cheaper to obtain a new one than to try and form one. Except in cases of minor buckling, it will generally be necessary to remove the bottom as well as the deck in order to replace a section of bulkhead properly.

Repairs after Serious Crashes.—As long as either the deck or the keel of the floats remains straight and the whole structure has not been hogged and

buckled, repairs in the field can generally be made as already described. A pontoon that has actually been buckled in a crash, however, is very difficult to repair without replacing it on an assembly jig, since a whole section will probably have to be removed. If the damage appears to be of such a very serious nature, it is advisable to have photographs taken from several angles and sent to the factory with as complete a description of the damage as possible, so that detailed advice can be given.

Sometimes as a result of a serious crash, or where the propeller has cut through the float due to a strut failure, it is found that the bow of the float is hopelessly damaged while the rest of it may be in excellent condition. In cases of this sort it may be practical to cut away the entire damaged portion and splice on a new section supplied from the factory.

Repairing Struts.—In the case of crack-ups where struts and spreader tubes have been damaged, the struts which are made of un-heat-treated steel can generally be repaired by welding on reinforced sleeves or patches of ordinary aircraft sheet steel or tubing, but it is important to be sure that

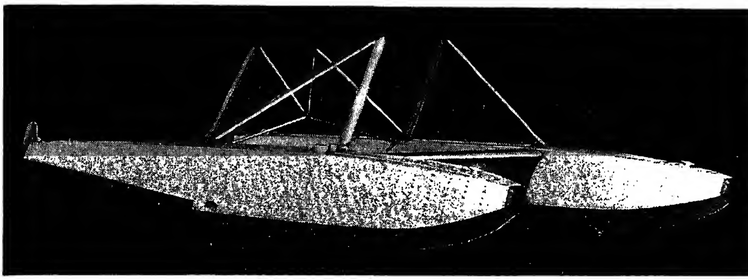


FIG. 29.—A pair of Edo floats ready to attach to a plane.

repaired struts are oiled inside, drained, and hermetically sealed so as to prevent internal corrosion. Most of the floats of modern design are built of dural, which is lighter. The spreaders are either of dural or of heat-treated steel. Obviously, such parts cannot be welded without destroying their strength, and factory replacements are generally required. For these reasons it is advisable to secure factory advice before attempting strut repairs. A temporary repair for flying to a base can sometimes be made either with steel tube or wooden reinforcements.

Ordering Parts.—In ordering parts it is important that the *exact model* and *serial number* of both the *floats* and the *aircraft* be supplied in all cases, together with *specific information as to the exact parts required,* and where possible the *part numbers* shown on the installation drawings or packing sheets should be indicated. Float parts are named in Fig. 28.

In describing material for float repairs, such as sheets and bulkheads, locations on the float should be identified in inches aft of the bow of the float (to be taken from the front of the nose bumper). In ordering strut fittings always identify them as being on the right- or left-hand side of the ship; as being on front, diagonal, or rear struts; and as being at the float end or fuselage end of the struts. A sketch is often helpful. The following definitions of float parts may be of service:

Keel—The outer wearing surface on the bottom of the float forward of the step on which the float slides on ramps.

Keelson—The interior extruded section, which takes and distributes the keel loads and to which the keel is attached.
Sister keelson—The interior extruded sections midway between the keel and the chine of the float.
Chine—The extruded section joining the bottom and the side sheets.
Deck clamp—The extruded section joining the deck and the side sheets.
Skeg—The extension of the keel aft of the step to keep the floats from rocking over backward on level ground.
Transom—The bulkhead at the stern of the floats to which the water rudders are attached.
Spreader tubes (front and rear)—The two tubes running between the floats and joining them.
Spreader wires—The cross brace wires running between the spreader tubes in the horizontal plane.

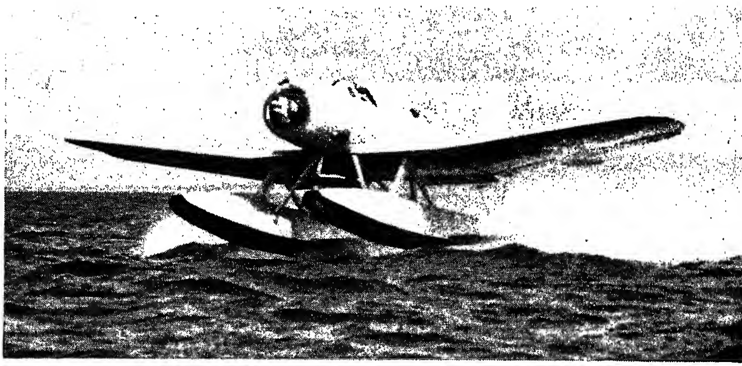


FIG. 30.—Edo floats on Navy Vought-Sikorsky scout bomber.

Strut wires (front and rear)—The cross brace wires running between the floats and the fuselage of the ship in the vertical plane.
Axle tube—The tube running across each float just forward of the step at the chine which is used for beaching axles.
Hand hole covers—Usually in the shape of a round plate held to a hole in the deck by a central screw and spider; on some larger models square plates are screwed on.
Access plates—The covering plates over openings in the decks which are large enough for a man to pass through; they are not used on small floats.
Bilge system—Pipes leading from the deck to the lowest point in each compartment; they are not used except on large floats.

Figure 29 shows a pair of floats ready to be attached to a plane; Fig. 30 gives some idea of the stresses to which they are subjected and the punishment they take even on comparatively calm water. This is greatly increased in rough water.

SECTION XVII

CONSTRUCTION DETAILS

SPLICING WIRE CABLES

Although the modern plane has almost entirely eliminated the use of wire and struts, as in the old wooden planes, there is still a need for the splicing of small wire cables in connection with the various controls on the plane. The cable ends are spliced after being bent around a thimble such as is shown in Fig. 1. The thimbles are of steel and cadmium plated as a protection against rust. As they are made to suit different diameters of cable, the proper thimble should always be used.

Kinds of Cables.—Three kinds of wire cable are in common use: a rather stiff, or nonflexible, cable known as the 1 × 19, which means there is one strand of 19 wires; it is strong for its size and has a minimum amount of stretch. Next is the 7 × 7 cable with 7 strands of 7 wires in each strand; this gives 49 wires instead of 19 and makes a more flexible cable. Then there is extra flexible cable, the 7 × 19, with 7 strands of 19 wires each—133 wires in all. Each wire is, in consequence, much smaller for the same diameter of cable. This adds greatly to its flexibility but makes it more liable to abrasion. All these different factors must be considered in selecting cables for different uses.

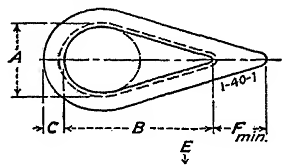


FIG. 1.—A typical steel thimble.

Cables are measured across the largest diameter. This means across the high spots rather than across the flats made by two of the strands. The seventh strand is always in the center with six strands around it.

Large planes generally use the 7 × 19 cables. Light planes frequently use the 7 × 7 cables for many of the main controls. The 7 × 19 cable is not made under 1/8 in. in diameter; the sizes in most common use are 1/8, 5/32, and 3/16 in.

Splicing Clamp.—After the proper thimble is secured, the end of the cable is bent around it, allowing enough wire to splice or weave into the cable itself, as in Fig. 2. This shows a common type of splicing clamp which holds the cable firmly against the end and sides of the thimble. It takes considerable practice to make a good splice in a wire cable, but it is the most satisfactory method for fastening the ends. A good man can make a splice in about 20 min. in the shop; it takes 50 per cent longer on the plane.

The strands of the cable outside the clamp must be opened with a suitable tool and the stranded ends passed through and drawn tight. The tool used is called a "marlinspike" and must be smooth so as not to scratch or abrade the wires. The cable is held in a vise so that it can be pulled taut by the clamp as the splice is being made.

The strands are tapered at the ends as the splice is finished in order not to leave an abrupt end to the splice itself. The splice is then wound tightly with a strong, hard cord, such as is used in marine work. Some call it "rib-stitching" cord. When the splice has been completely covered, as in Fig.

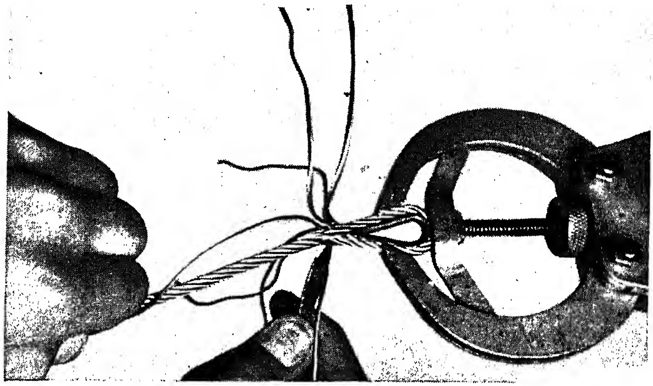


FIG. 2.—Starting the splice aroung a thimble.

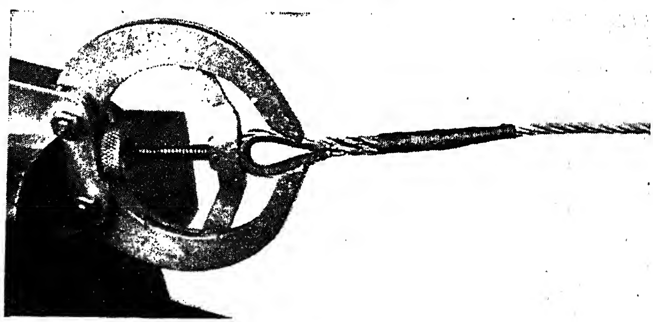


FIG. 3.—Splice finished and wrapped.

3, and the ends of the wrapping drawn inside, the wrapping, or serving, is shellacked. Cables should never be painted as paint interferes with proper inspection; they can, however, be greased or coated with a clear metal varnish.

Loops.—Loops in single wires are also necessary at times and are standardized, as shown on page 669. These are much easier to make than a splice but at the same time require much practice for a good job. There is some-

times a tendency to make the loop too long and too large as in Fig. 4. When pulled taut, it lengthens out and is not satisfactory. A much better proportion is seen at the right. The proper proportions are shown in the diagram and in Table 36 on page 763.

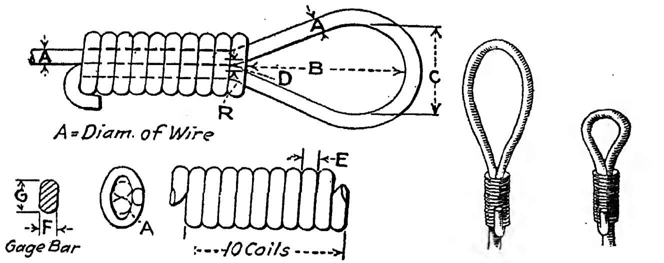


FIG. 4.—Looks—good and bad.

Ferrules for use with loops of this kind are made from wire coiled over a form or gage bar, as shown. It is cut into lengths of 10 coils for use as ferrules. The ends should be smoothed to remove any rough ends. The end of the wire is bent back after being pushed through the loop, as shown. These are better in every way than sheet-metal ferrules. Turnbuckles are wired to prevent turning, or unscrewing, after they are in place. This should be done carefully.

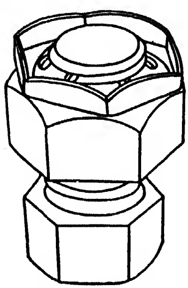


FIG. 5.—"Palnut"—a form of lock nut largely used in airplane work.

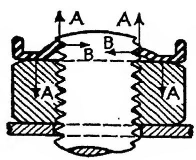


FIG. 6.—This shows the action of a palnut against a bolt and nut.

PALNUTS

Various methods have been devised for preventing nuts from becoming loose. Lock nuts have been designed by the hundreds, but few have found a place in industry. The castle nut has become the standard fastening in the automobile industry and is largely used in airplane construction.

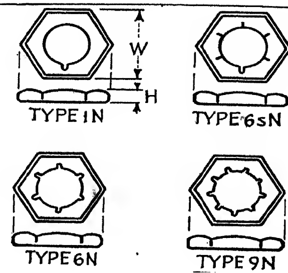
During the last few years another lock nut has been widely used by builders of airplane engines, especially for *outside nuts*. These are known as palnuts, made by The Palnuts Co., Irvington, N.J. These nuts are of pressed steel, as shown in Fig. 5, hardened and tempered after forming. The forming gives the nut a single thread and the slots permit each jaw to grip the thread as the palnut is screwed down on top of the regular nut.

The action of these jaws puts a spring tension on the nut and also against the thread of the bolt or screw, as shown by the arrows in Fig. 6.

Table 1.—Dimensions of Palnuts

American standard machine screw sizes				
Diam. of screw, in.	Threads per in.	W,* width across flats, in.	H, height or thick-ness, in.	Type
No. 3 (0.099)	48	3/16	0.062	1N
No. 4 (0.112)	36	1/4	0.078	1N
No. 5 (0.125)	40	1/4	0.078	1N
No. 6 (0.138)	32	1/4	0.078	1N
No. 6 (0.138)	32	5/16	0.089	6sN
No. 8 (0.164)	32	11/32	0.095	6sN
No. 10 (0.190)	32	3/8	0.102	6sN
No. 10 (0.190)	24	3/8	0.102	6sN
No. 12 (0.216)	24	7/16	0.110	6N
No. 14 (0.242)	24	1/2	0.120	6N

Types



Bolt diam., in.	Threads per in. (coarse thread)	American standard heavy nut sizes (U. S. standard): W, width across flats, in.	H, height or thickness, in.	Type	American standard regular nut sizes (American standard): W, width across flats, in.	H, height or thickness, in.	Type
1/4	20	1/2	0.120	6N	7/16	0.115	6N
5/16	18	19/32	0.138	6N	9/16	0.138	6N
3/8	16	11/16	0.156	6N	5/8	0.151	6N
7/16	14	25/32	0.174	6N	....	.....	...
1/2	13	7/8	0.191	6N	13/16	0.190	6N
5/8	11	1 1/16	0.230	6N	1	0.228	6N
3/4	10	1 1/4	0.270	6N	1 1/8	0.245	6N
7/8	9	1 7/16	0.290	6N	1 5/16	0.270	6N
1	8	1 5/8	0.326	6N			
1 1/8	7	1 13/16	0.360	6N			
1 1/4	7	2	0.390	6N			
1 1/2	6	2 3/8	0.450	6N			
1 3/4	5	2 3/4	0.515	6N			
2	4 1/2	3 1/8	0.570	6N			
2 1/4	4 1/2	3 1/2	0.640	6N			
2 1/2	4	3 7/8	0.695	6N			

Bolt diam., in.	Threads per in.: Fine thread (S.A.E.)	Coarse thread	American standard light nut sizes: W, width across flats, in.	H, height or thickness, in.	Type
1/4	28	20	7/16	0.115	6N
5/16	24	..	1/2	0.128	9N
3/8	24	..	9/16	0.139	9N
7/16	20	..	5/8	0.150	9N
1/2	20	..	3/4	0.171	9N
9/16	18	..	7/8	0.192	9N
5/8	18	..	15/16	0.205	9N
3/4	16	..	1 1/16	0.220	9N
7/8	14	..	1 1/4	0.247	9N
1	14	..	1 7/16	0.277	9N

* Dimension *W* is maximum allowable. Tolerances are all minus.

PLASTIC WINDSHIELDS AND WINDOWS

Transparent plastics are used in place of glass in windshields and windows, on account of weight and fracture. Plexiglas is a popular material for this purpose. Although fully as transparent as glass, it is comparatively soft and scratches much more easily. To protect the sheets before they are installed, they are shipped with a paper covering on each side, which should not be removed until the sheet is in place in the plane.

CARE OF PLEXIGLAS

Plexiglas sheets on leaving the factory have highly polished surfaces. Great care should be exercised to prevent accidental scratching or marring

of unmasked sheets by handling the material with dirty or greasy hands. After inspecting the Plexiglas, make sure that its surface is free from adhering dirt, and paste a piece of paper over both faces of the sheet. Gelatin[1] dissolved in water to give a thick paste and any porous paper will serve. In pasting the paper on the Plexiglas, be careful not to slide the paper over the Plexiglas, as particles of grit in the paste may cause scratches. The sheets should be left overnight in order that the gelatin may dry.

The paper can be left in position while the sheets are being cut to shape. It is highly recommended that the masking not be removed until the finished article is ready for installation. Of course, the masking paper must be removed if the Plexiglas is to be formed into curved shapes. The paper can be removed by easing one corner from the Plexiglas sheet and pulling gently.

Small patches of gelatin remaining on the surface are washed off by leaving the sheet in warm soapy water for a short period of time, rubbing gently with the hands, and then immersing in clean water. To dry the sheet, pat or blot with a very soft cloth or absorbent paper. Hard fabrics must not be used. The supports in the washing tank should be rubber covered.

Removing Dirt and Grease.—If Plexiglas becomes soiled with grease and oil, solvents for these substances, such as kerosene or naphtha, may be used to remove dirt. However, sprays that are commonly employed in cleaning glass window shields must not be used as cleaners, since they may contain solvents for Plexiglas.

A water solution of Dreft or Drene is highly recommended for washing grease, oil, or dirt from Plexiglas. These compounds can be obtained from any drug or department store. A small quantity is dissolved in water, making a very soapy solution. Plexiglas is then cleansed by rubbing gently with a soft cloth, in a manner similar to cleaning window glass, rinsing the Plexiglas in clean water, and finally drying.

Cleaners that contain abrasives must *never* be used on Plexiglas, for the abrasives will scratch the surface. The use of solvents, such as acetone, ethyl acetate, benzene, ethylene dichloride, etc., to brighten the surface of Plexiglas is never recommended since these substances soften the surface of the plastic.

Hand Polishing. *Minor Scratches.*—The most effective polish for the removal of minor scratches is Simoniz Kleener.[2] The Kleener is applied with a damp, soft cloth, and only the scratched area is rubbed vigorously. Caution must be taken not to rub in one place for any length of time, as friction will build up heat and cause ridges. Rub both in the direction of, and at right angles to, the scratch. Several applications of Kleener may be necessary. When the scratches are removed, or considerably improved, remove the Kleener with a damp, soft cloth.

Simoniz polish should now be applied. Use about ½ yd. of soft cloth. Wet it, wring it out almost dry, and fold into a pad, approximately 6 in. square. Apply the Simoniz polish to the surface, evenly and thoroughly. Let it dry a few seconds, and then rub lightly with a dry, soft cloth.

Polishing cloths should be clean, soft, and grit free. It is recommended that the new cloths be washed with soap and clean water, rinsed thoroughly, and allowed to dry in a dust-free room.

[1] Other adhesives besides gelatin may be used, such as pressure sensitive rubber adhesive (from Alden Rubber Co. Philadelphia, Pa.; and Maskite, Corp. Los Angeles, Calif.).

[2] Lincoln cleaner available at any Ford Motor sales office may also be used.

It is not necessary to remove Plexiglas from frames when the hand method of polishing is used.

Deep Scratches.—The area surrounding the scratch should be sanded with No. 320A, or finer sandpaper, obtained from Minnesota Mining Co., St. Paul, Minn., or local hardware stores. The area to be sanded will be determined by the depth of the scratch or scratches. In all cases the sandpaper scratches must not exceed the depth of the original scratch. It should be remembered that an abrasive that will put many fine scratches in the sheet is being used, while one or more medium deep scratches are being removed.

After sanding, proceed under steps outlined for polishing minor scratches by hand, using Simoniz Kleener and finally Simoniz polish.

Mechanical Polishing.—All steps in the polishing operation should be carried out over as limited an area as practical, and by rubbing and buffing in all directions. Machine marks should be taken out by the use, in progressive stages, of No. 210 Flint paper, and No. 320A sandpaper. After the machine marks, or rough surfaces, are removed, all dust and grit should be washed from the article, in order to prevent contamination of the buffing wheel.

Use a 10-in. diameter 3/16 in. laminated, stitched hard felt buff, revolving at 1,200 r.p.m. A 1200-r.p.m. Companion Pencil Drill (available from Sears, Roebuck and Co.) may be used for driving buffing wheels.

Wax candle or paraffin applied to the surface of the felt buff acts as a good binder for the abrasive.

Apply dry Udylite X-54 coloring compound.[1] (Udylite Co., Detroit, Mich.) to buff. Press the article to be polished lightly against the surface of the buffing wheel. Do not try to force the operation by the application of pressure. An even distribution of the buffing action is necessary to avoid distortion. This buffing action should be continued until all but the finest scratches have been removed.

Clean Plexiglas thoroughly to remove all of the abrasive, and polish by hand using Simoniz polish.

Polishing Irregular Articles.—Use an 8-in. loose white cotton disk, with about 50 disks revolving at 1,200 r.p.m. A Companion Pencil Drill, described above, may also be used here. Cotton disks for buffing wheels may be made from plain white cotton sheeting.

As an abrasive, a thin paste made from water and magnesium carbonate, obtainable from a drugstore, is used. The magnesium carbonate and water are mixed into a paste having the consistency of thin cream, allowed to stand for 5 min., and decanted into a clean vessel, leaving behind the coarse hard particles which would scratch the Plexiglas. The paste may be applied to the buff with a brush. Keep the brush and paste in a sealed dirtproof jar.

Saturate the buff with the magnesium carbonate-water paste. Additional damp paste may be applied while the buff is in use. Buff the surface lightly. The saturated, spinning wet buff assumes the shape of the irregular object, and in this manner the cuts may be polished. Wash with soap and water, dry with soft cloth, and polish by hand using Simoniz polish.

Recommendation.—Generally, the last operation in finishing a Plexiglas piece is done by hand and consists of polishing the Plexiglas surface with

[1] Udylite X-54 has been found most satisfactory although in some cases it has been advisable to use a little tallow on the buffing wheel along with the coloring composition; also White Buffing Compound No. 9-2876, available from Sears, Roebuck and Co. may be used; and No. M-157, made by Hanson-Van Winkle Co., Matawan, N. J., which contains a little more tallow.

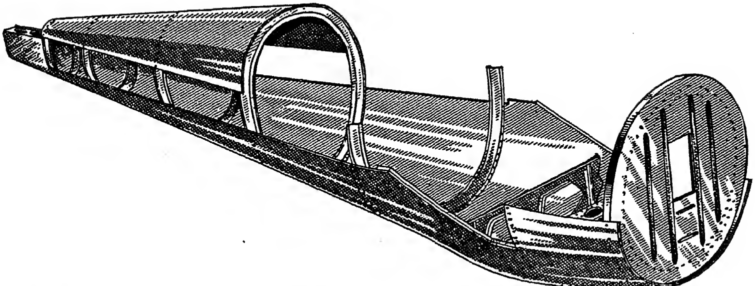


FIG. 7.—All-metal fuselage of monocoque design used in small planes.

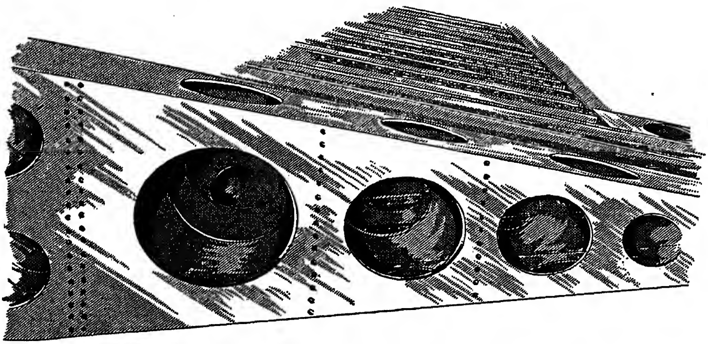


FIG. 8.—Aluminum-alloy wing-rib construction used on Douglas B-19 bomber which has a wing spread of 210 ft.

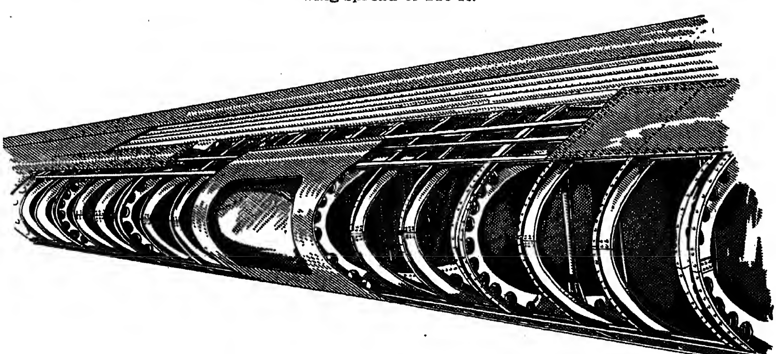


FIG. 9.—Leading edge of the wing of the same bomber before covering.

Simoniz polish. It is strongly recommended that a newly fabricated article be polished upon installation and regularly polished thereafter. A Simonized surface is easy to keep clean, and there is less danger of scratching the finish.

PLANE CONSTRUCTION DETAILS

An example of metal construction in small planes is seen in Fig. 7, which shows the fuselage of a monocoque design. The bulkheads have been

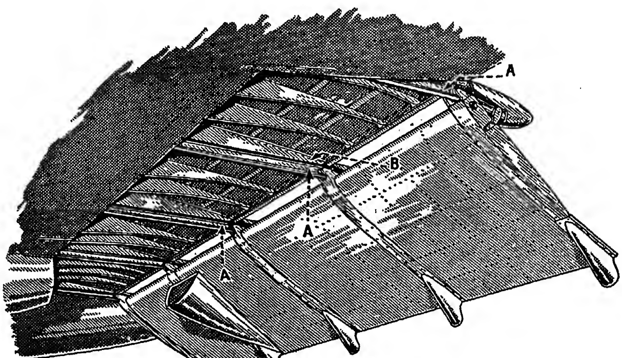


Fig. 10.—Fowler-type wing flap used in Lockheed planes.

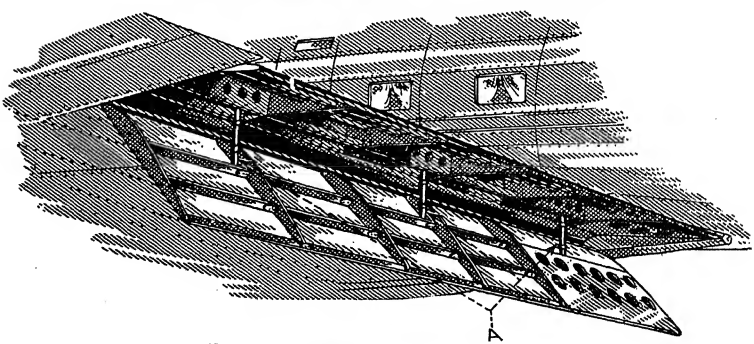


Fig. 11.—Douglas uses flaps of this type.

drilled previously, as have the sheets. These are of 0.032-in. No. 17ST Alclad which are rolled to shape and drilled ready for riveting.

Two details from a big Douglas B-19 bomber are seen in Figs. 8 and 9. The first shows the construction wing ribs which are built up of aluminum alloy. The wing spread is 210 ft.

Details of the leading edge of the wing is shown in Fig. 9. This shows the ribs before the sheet-metal covering has been put on. Every third rib is reinforced. The stringers are of H section. The opening shown is for one of the landing lights.

Figures 10 and 11 show two methods of making wing flaps. Figure 10 is the Fowler flap, used on the Lockheed planes, which consists of a small auxiliary airfoil located on the underside of the wing at the trailing edge. The flap slides back on tracks at *A*, being operated by the flexible cables *B*. The tracks are so shaped that when the flaps are at the back end, they are at the correct angle. The cables are hydraulically operated under control of the pilot.

Douglas uses another type of flap, which is seen in Fig. 11. These flaps are hinged at the front edge and hydraulically operated by the push rods shown at *A*. The hinge line of the flap is behind the rear wing spar.

SECTION XVIII

IRVIN AIR CHUTE

This, the best known parachute in this country, is of the free-fall, manually operated type. This means that it is carried as a complete unit with no attachment to the plane, but is strapped only to the aviator or passenger. Being manually operated, its opening is controlled by a release cord by which it can be opened at will when clear of the plane.

Special linen harness with tensile strengths of 3,000 and 4,500 lb., in different types, are used. Specially developed silk is used, woven to allow air to pass through it slowly. There is also a vent in the center which helps draw up the air under the chute. Shroud lines, also of silk, run from one side, over the top, and down the other side. These lines have a tensile strength of 450 lb.

A pilot chute, about 3 ft. in diameter, is attached to the top of the canopy. It has a spring frame that opens it as soon as it is released. In doing so, it pulls out the large chute; this is an added safety device.

Types of Pack.—Chutes, generally, are 24 and 26 ft. in diameter; other sizes are 22 and 28 ft., the larger being used for exhibition and training jumps. The 24-ft. chute may be called standard. Both the 24- and 26-ft. chutes are packed in six types of container. They are the seat pack, front suspension pack, straight back pack, form-fitting back pack, quick-connector pack, and the chair chute pack.

The weight of the 24- and 26-ft. Irvin chutes, with harness and container, is about 21 lb. The average rate of descent is about 18 ft. per sec. The 28-ft. chute rate is about 16 ft. per sec. The average time for a chute to open completely is less than 2 sec.

The various types of parachutes are made to suit different services. The seat pack is used as a cushion on which the aviator or passenger sits. It relieves the body of all weight while in the plane.

The front suspension pack was developed especially for the use of machine gunners and photographers. They usually have the most room directly in front of them and below the waist line.

Straight back packs are made to fit the back closely. They are particularly designed for use in lighter than air ships so as to permit climbing about inside the ship.

The form-fitting back pack resembles the straight back pack but fits the form more closely and is much more comfortable to wear. Some aircraft construction makes this type of pack highly desirable if not absolutely necessary.

There is also the chair seat pack designed to be adaptable to any type of airplane chair. It remains invisible until needed but is just as efficient as the other types.

In all these packs the parachute itself is folded and cared for in substantially the same way. All types require extreme care in folding and handling, for any lack of precaution may mean failure in opening.

Packing Chutes.—It is of course necessary that the chutes be packed carefully; the method of doing this is shown in the illustrations that follow.

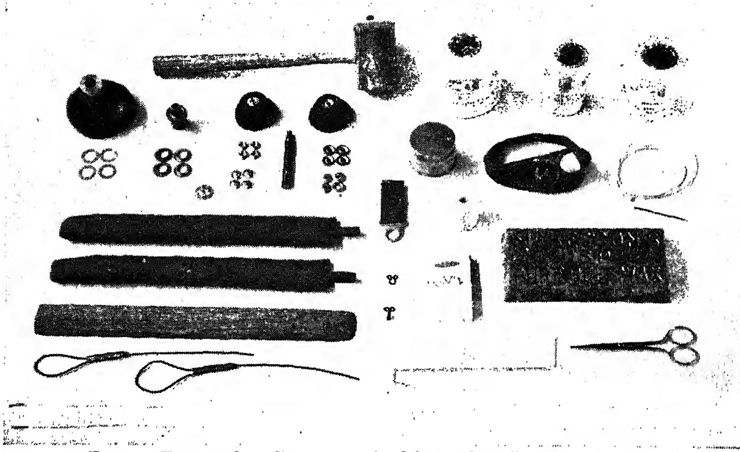


Fig. 1.—Tools and appliances provided for packing Irvin air chutes.

Fig. 2.—Canopy completely folded. Weighted shot bags hold the folds on the right side.

Special packing equipment (Fig. 1) is provided and full instructions are given with each chute. The general method is shown in Figs. 2 to 6. Packing sticks are used to tuck in the flaps and remove the wrinkles. A special packing hook is used to draw the shroud lines into their pockets in

the container. It is made of hard wire 1/8 in. diameter and 12 in. long. It should be made very smooth to prevent snagging the fabric.

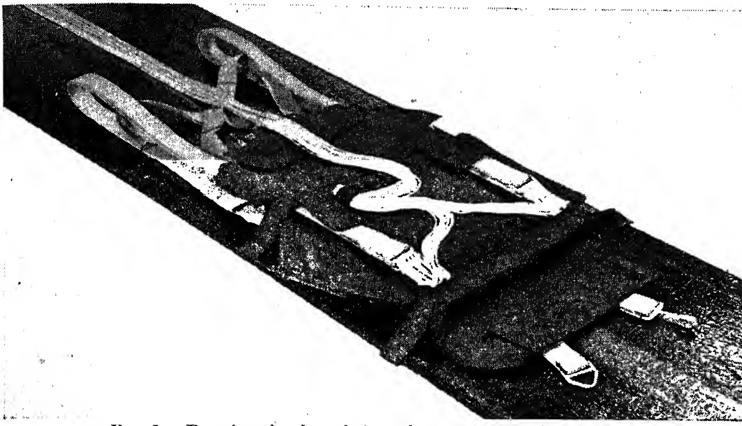


FIG. 3.—Drawing the shrouds into their pockets in the seat pack.

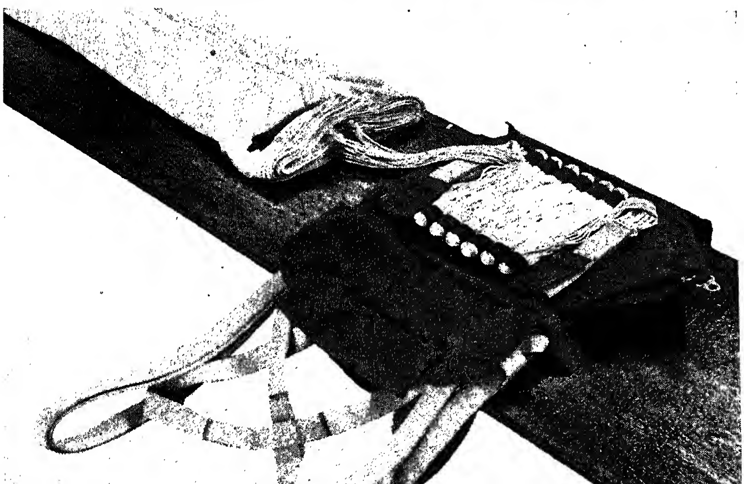


FIG. 4.—Straight back pack with shroud lines in place.

The pleating of the canopy is best done on a table 3 ft. wide and 45 ft. long. In Fig. 2 the canopy has been completely folded. The folds should

FIG. 5.—Canopy folded on a seat-pack container. Rip cord is at the right.

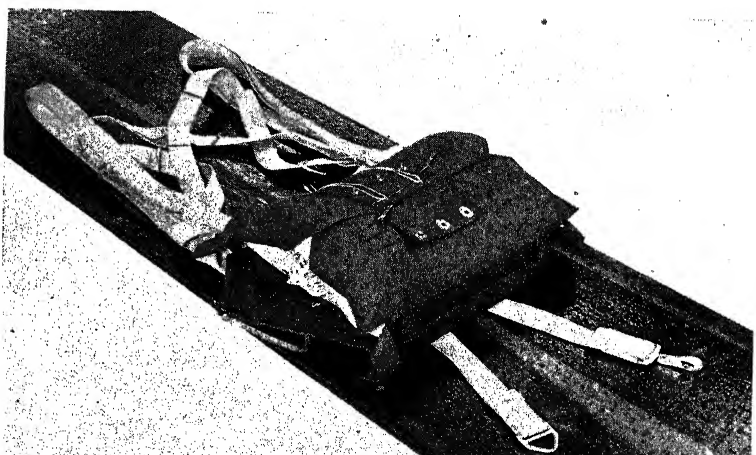


FIG. 6.—Sides of canopy container have been drawn together. They are held by wire pir

be even and there should be no wrinkles in the silk. Shrouds should also be one above the other as shown.

Figure 3 shows the first loop drawn into the retainer pocket of a seat pack. In the back pack these pockets are at the side, as shown in Fig. 4, where all the lines have been put in place.

In Fig. 5 the canopy has been completely folded, care having been taken to remove the two shot bags used while it was being folded. The rip cord is at the right and below the canopy.

The sides of the container are drawn together and, with the aid of cords, the locking cones are pulled up through the grommets. Secure each cone *temporarily* by inserting a wire pin through each hole in the locking cones. These pins were shown in Fig. 1. Do not remove the cords. Have the

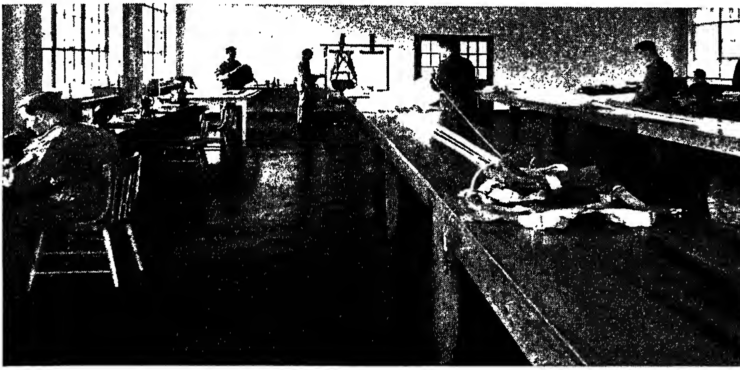


Fig. 7.—Parachute table at Mitchel Field, N. Y. (*Official photograph, 2d Air Base Squadron.*)

handles of the pins toward the center of pack as in Fig. 6. This makes it easier to remove them when rip-cord locking pins are placed in the locking cones.

Next, close the end from which the rip cord enters, after making certain that the pilot-chute flaps are in proper shape. Then insert the rip cord in its housing. This applies only to the seat pack. Insert both cords through grommets in the tab end of the container and draw the tab in place over its locking cone. Remove the temporary wires and insert the rip-cord locking pin. Before closing the open end, be sure the canopy is not disarranged.

Figure 7 shows the parachute table used at Mitchel Field, N. Y.

CARE OF THE IRVIN AIR CHUTE

The saving of over three thousand lives in emergencies, as well as many thousand successful drop tests, proves conclusively that the Irvin air chute will invariably function properly under the most unfavorable conditions. However, to ensure that its operation remains at peak efficiency, it must naturally receive reasonable care and attention.

Each aviator should have an air chute permanently assigned to him; in this case he will take a greater personal interest in its care.

Inspection.—If the chute is constantly worn but not used, it should be taken from its container, shaken out, and repacked at least once each 30 days.

Injurious substances such as acids, oils, and chemicals, must not be permitted to come in contact with any part of the air chute or harness. In packing or making tests or live drops, the air chute may become soiled by dust, grass stains, etc. This will not impair the strength of the material or the manner of operation, but reasonable care should be exercised to keep the silk fabric and shroud lines clean and free from foreign matter.

Washing is not recommended. Ordinary soiled spots and stains of a harmless nature may be allowed to remain. Grease and other substances of an injurious nature should be removed with carbon tetrachloride or a similar solvent that will not injure the fabric.

If the air chute drops into salt water, it should be rinsed with clean fresh water, preferably soft water, and dried as soon as possible. This is best done by suspending the chute full length from the apex and spraying with fresh water from a hose, after which it should be allowed to dry naturally while suspended in a shady place. *Do not wring water out by twisting fabric.*

Any air chute that has been dropped into water a number of times should be carefully inspected to determine whether any deterioration has set in.

Packing is best accomplished on a clean, smooth surface. If done on the ground, a piece of cloth of suitable size should be spread out; if this is not available a clean, dry grassy spot may be selected on which to pack. Naturally the air chute which has been best cared for and correctly packed will outlive one receiving insufficient and improper attention.

The Container.—Complete inspection should take place at regular intervals. Practically all wear and tear resulting from service usage comes on the container. Examine it for fabric tears, chafing, loose parts, etc. Locking cones, grommets, and tabs must be in place and in excellent working condition. Any that are damaged or badly worn must be renewed. The rip cord must have no frayed strands, bent locking pins, or loose joints. See that the rip cord housing has not become crushed or has not torn loose from its anchorage on the container or harness.

The function of the rip cord housing is to protect the rip cord and thereby prevent accidental release of the air chute. Its length in relation to the rip cord is such that when properly attached, any tension applied to the harness or rip cord will not be transferred to the rip cord itself. The correct attachment of the rip cord housing as well as the pocket holding the rip cord pull ring is of prime importance and must receive close attention when making repairs or replacements.

To determine whether the attachment is correct, pack the air chute and place the rip cord in its normal position with the pull ring in its pocket. Steady the container with one hand while with the other hand jerk the harness strap (to which pocket is attached) in various directions; also lift the pack by the rip cord housing. During the operation watch each locking pin closely to see if it has any tendency to withdraw from the locking cone. If the locking pins remain firmly in place, the attachments of the rip cord housing and pull ring pocket are correct.

The Pilot Chute.—Examine the pilot chute for proper tension in the opening springs. It is imperative that these springs are not corroded in any manner and the frame is not loose. Check each fitting and hinge to see that all pins are in proper position. Note that the ribs have not worn through their pockets. Ascertain the condition of each shroud line and the

loop at the bottom of the shroud lines. If there are any broken or frayed strands, repairs must be made.

Renew pack opening elastics wherever they become weak. Their function is to assist in drawing back the flaps of the container after the locking pins have been removed from the locking cones thus permitting the air chute to free itself into the air more quickly.

When an air chute is to be removed from service or is to be stored, it should be released from its container, loosely rolled up, placed in its travelling bag, and stored in a clean, dry place, preferably in a room where a moderate temperature is maintained.

All air chutes, regardless of make, operate in a similar manner and must have the best of care.

SECTION XIX

INSPECTION AND MAINTENANCE

You may drive your car until it falls apart, unless you live in one of the few states where periodic inspection is compulsory. But all airplanes, large or small, must be inspected after a given number of "flight-hours" as regulated by government rulings. All air transport lines have set up their own checking periods, working in conjunction with the government regulating body, the Civil Aeronautics Administration, or C.A.A., as it is usually called.

In the early days of aviation an engine was torn down for complete inspection after 50 hr. in the air, if it had not come to grief before. Now an engine runs from 500 to 650 hr. before a complete overhaul, being replaced by a new, or a rebuilt, engine, so as to keep the plane in service.

The different air lines have worked out very elaborate standards for the inspection of various parts. Although these vary to some extent, the bulletin from the Eastern Air Lines (page 689) may be considered typical.

It is customary to divide repair bases into separate departments, or shops. That of the United Air Lines at Cheyenne, Wyo., may be taken as typical. Here they have shops, or divisions, with the following headings:

Plane overhaul	Cabin overhaul
Engine overhaul	Propeller overhaul
Sheet-metal shop	Machine shop
Radio shop	Instrument shop

Suitable subdivisions are made to conform to the kinds of work to be done, and each shop, or division, has machine equipment best suited to the work to be done there.

Generally speaking, the planes are dismantled in the following order: The propeller comes off first; then the engines; the wings follow; leaving the fuselage and landing gear. Each section of the shop has its crew, specially trained for the work it is to do.

AIR-LINE MAINTENANCE

An excellent idea of maintenance of transport line planes can be had from excerpts of a paper, presented before the S.A.E. by R. A. Miller, Supervisor of Overhaul, and J. F. Martin, Superintendent of Maintenance, both of the American Airlines.

The responsibility of the maintenance department of American Airlines is to maintain its fleet of airplanes in a constant state of airworthiness, assist the engineering department in the development of engineering changes on all operating equipment, cooperate in the decisions made regarding the specifications on proposed equipment, and to design, improve, and maintain all ground and station equipment that is associated with the maintenance and service of the airplanes and engines.

Airworthiness represents the guarantee that the airplane will function normally as designed, regardless of its age. An airplane is made airworthy on the ground and to do this we employ a system of "preventive maintenance" or the recognition of mechanical service life expectancy. We know how long a component

part can operate before any mechanical service or attention would normally be needed; therefore, every job is based on length of service and is accomplished before the critical time period is reached. Critical time is usually determined by actual observations of test runs and a complete record of research data on the item in question.

Inspection Made of 75 Items Daily.—A daily check of our aircraft is made at the termination of each ship's schedule assignment and it includes certain items that we know from experience are necessary. It includes a visual inspection of the aircraft for damage or defects, a check on fuel and oil capacities, lubrication of the landing gear, functional check of engines, brakes, electrical and instrument systems, and a general inspection of the interior of the ship. All of this work is done by or under the supervision of certificated mechanics. A form is provided for this check and some 75 items are checked and certified by the mechanic's signature. In addition to this routine check the flight report made out by the pilot on the last flight of the airplane is thoroughly checked and any items listed for attention are investigated and remedied.

A base inspection is a duplication of the daily check plus certain items such as a complete change of all 36 spark plugs and a more detailed inspection and service of those items that we know from experience will need attention after 50 hr. of flight which is approximately 9,000 miles of service.

The major inspection is quite comprehensive for, in addition to the work done on the daily and 50 hr. inspections, considerably more procedure is effected. On this check the ship is jacked up and teardown is made for inspection of the landing gear, wheels, brakes, tires, and bearings and the brake system plumbing. The oil is changed in both engines; the engines are checked for cylinder compression; valve clearances are checked and reset if necessary; fuel quantity gages are checked for accuracy; and, as the landing gear retraction, automatic pilot, landing flaps, and brakes all are operated by hydraulic power, thorough inspection and individual performance check are made of each of these units with relation to the proper operation of the hydraulic system.

While this maintenance work is being done, the fleet service section of the maintenance department cleans and refits the ship both inside and out. We find it practical to maintain high standards of appearance by regularly polishing the exterior surfaces of the ship. The polishing is scheduled to be accomplished once a month requiring approximately 80 man-hr. per ship. We feel that an airplane must never show its age, and it is toward that end that we direct our efforts in this work.

Engines Torn Down at 600 Hr.—At 600 hr. the power plants are removed for complete inspection after teardown, reassembly with new and reconditioned parts, and performance test before being put back into service. A power plant is the engine, propeller, carburetor, starter, generator, magnetos, fuel and hydraulic pumps, motor mount, plumbing, wiring, oil radiator, and other miscellaneous equipment associated with the complete engine unit. The power plant is removed from the ship together with the engine cowling, is disassembled, and the various component parts are routed to various shops . . . After the engine has cleared through inspection, rejected parts are replaced from stock and usable parts are reconditioned. The engine is now assembled with all its accessories into a power plant unit ready for test run . . .

Ships Rebuilt after 5,500 Hr.—The other jobs allocated to other time periods between 600 and 5,500 hr. overhaul are items that have a relatively low trouble factor such as replacement of all rubber hydraulic lines at 1,250 hr., certain structural inspections at 2,000 hr., and replacement of electrical system master and selector switches at 2,500 hr. At 3,000 hr. we remove the wings for better inspection of concealed structure. We replace all landing gear shock struts with newly overhauled and tested struts and remove gas tanks and treat the interiors of the tanks with a corrosion-resistant material after a thorough check and inspection. The entire control system, comprising both airplane and engine controls, is given a close inspection for cable wear at this time and if an inspector finds an item needing attention, it is recorded for completion by a mechanic.

We are constantly repeating these inspections taking corrective action when necessary until the ship reaches about 5,500 hr., at which time it is laid up for a

complete rehabilitation. The interior of the ship from the pilot's cockpit seats to the ladies' powder lounge is reconditioned by a corps of painters, upholsterers, glaziers, structural mechanics, electricians, hydraulic experts, assemblymen, and radio technicians. All aircraft equipment is modernized at this time and improvements that have been already made standard on later production models on each particular ship are incorporated into the ship being overhauled.

Maintenance Well Organized.—The maintenance department of American Airlines, supervised by the superintendent of maintenance in New York, is organized generally into five divisions or suborganizations. These divisions are under the direction of maintenance supervisors in New York, Chicago, Ft. Worth, and Los Angeles, each of them being responsible for all maintenance activities in his own particular geographical sector, and the supervisor of overhaul in New York who is in charge of all base shop activities.

A supervisor of maintenance regulations, also based in New York, is responsible for the origination of all paper work in connection with instructions, bulletins, and approved procedures regarding all phases of maintenance and administration. All contacts and arrangements regarding the assistance and cooperation of the C.A.A. for problems on relicensing of aircraft and compliance with regulations are made through this office.

All fleet service activities are under the supervision of the fleet service section of the maintenance department and are responsible for the interior and exterior condition of the airplane, completely equipping the airplane with all items from hot and cold food boxes to the latest airline timetables and from clean cabin rugs to freshly laundered berth linens.

The actual functions of radio maintenance do not come under the organization of the maintenance department. The radio department operates as a distinct and separate unit of the operations department performing all construction and repair work in their own shops. All work of a major structural assembly or sheet-metal work is accomplished, however, by the maintenance department on such jobs as mounting the antennae masts or installing radio compartments and is under the supervision of the maintenance department foremen and inspectors.

We have 1,300 employees in the maintenance department of American Airlines, of which 85 are in supervisory capacities, 25 are inspectors, 575 mechanics of all classifications, 140 apprentice mechanics, 325 fleet service personnel, and the remainder in the classifications of fuel and oil servicemen, clerks, parts washers, porters, etc. This distribution of maintenance department personnel gives us an average of 16 ground personnel in maintenance alone, discounting all other departments, for every airplane in service.

It is an accepted fact that the best way to train the skilled worker is by means of a sound apprenticeship plan. Several years ago, American Airlines inaugurated an apprentice-training program starting with 40 apprentice mechanics. Today there are 140 apprentice mechanics in training all over our system, approximately one new man admitted to the training program per week since its inception.

Extensive Training Program.—Apprentice programs vary in elapsed time from 3 to 6 yr. depending on the trade involved, number of working hours per month, etc. American Airlines' apprentice-training program is a four-year plan. Credits for past experience, not to exceed one year, are extended to those apprentices who have had prior training or experience in the military services of the United States or training in any one of the various approved aeronautical schools throughout the country.

A sound training program of this nature necessarily starts with a careful selection of the individual from the applicant list. If a young man is in sound physical condition, single, between eighteen and twenty-four years of age, an American citizen, a high-school graduate, is inherently mechanically inclined, is not afraid of hard work and is ambitious, has good appearance, possesses a fair share of common sense, has some originality, is willing to learn, and in addition, has a good family background, he meets our minimum requirements. Our apprenticeship group consists of four different classifications: (1) the radio maintenance and overhaul apprentice mechanic, (2) the instrument overhaul apprentice mechanic, (3) the engine overhaul apprentice mechanic, and (4) the general apprentice mechanic.

The first three groups receive all their entire four years of training in their respective departments whereas the fourth group, the general apprentice classification, who represent the majority of our apprentices, receive a variety of experience. We have about 100 apprentices in this group at present. This apprentice's training and experience is directed toward making him a seasoned line maintenance mechanic and is secured by rotation through all of our various shops and departments with the exception of radio. . . .

Classroom Lectures Included.—The daily work experience in the shops is further supplemented by related classroom instructions in the evenings for all apprentice mechanics. Each apprentice receives a minimum of approximately 16 hr. per month, in classroom work. This instruction is given in some cases by instructors employed from outside the company and then again by our own lead mechanics, inspectors, and foremen. In other words, we felt that our mechanics are better qualified to instruct on certain phases of engine accessories, for example, than an employed instructor inasmuch as some of this equipment is on Governmental restricted lists and, therefore, is not available to the general public; then again, some of it is rather expensive for the average aeronautical school to purchase for instructional purposes. These apprentices, as well as the instructors from within our own ranks, are paid their regular hourly rate for attendance at related classroom instruction. Specialized subjects such as welding, cable splicing, or proper operation of shop tools and equipment, are supplemented by actual classroom instruction that is carried on in the welding shop, cable department, or sheet-metal shop.

I might add, at this point, that in addition to the selection and training of apprentice mechanics, we in the maintenance department of American Airlines also have the responsibility of training apprentice engineers for our engineering department. These young men receive a condensed one year's training in our shops and departments working with the regular mechanics. This one year's practical experience plus their valuable technical backgrounds place these young engineers in an excellent position with respect to opportunities for rapid advancement in their chosen field. We find that the practical training gained from their close contacts with shop personnel and every-day aircraft shop problems proves to be invaluable in their later assignments as aircraft draftsmen or airline project engineers.

Further, the maintenance department conducts instruction classes and demonstrations for all new flight officers in the construction and operation of the mechanisms of the aircraft and its engines. This training, under the supervision of the maintenance instructor of flight personnel, is a part of the new flight officer's intensive 3-mo. training program given him by the company before he is assigned to a regular run as a first officer.

New Problems Ahead.—Future trends in airline maintenance, as they may apply to four-engine equipment and more extensive operations over the geographical surface of the earth, indicate that our maintenance control will be so organized that the aircraft will be available a greater number of hours per day than we now obtain from our present equipment. Owing to this requirement, it appears that before this airplane gets into airline service, detail study of the aircraft and engines and all of their components will have to be made by key personnel in the maintenance department during the construction of the aircraft so that when the airplanes are turned over to the air line for operation we will have our maintenance programs completely set up to guarantee sufficient knowledge of our personnel in the proper procedures to follow up and expedite the corrective action on items causing trouble. We are certain that one point will be the assignment and training of third crew members who will be responsible for the observation and inspection of all mechanical facilities of the aircraft that are accessible while in flight. The duties of these assignments will extensively broaden the scope of our training responsibilities embracing additional studies that must be investigated and organized so that they may be incorporated into our already established curriculum.

New designs and engineering developments will further specialize the required talents of our personnel. Substratosphere operations incorporating the use of "pressurizing" apparatus and leakproof cabins for passenger comfort at high

altitudes will open new fields of research and endeavor for mechanical ingenuity. Sustained performance of super charged engines at altitudes far above those flown in present-day operations will demand more rigid requirements of engines and accessories and, correspondingly, it will necessitate increased specialization in personnel adequately to provide the maintenance facilities and procedures to insure efficient engine operation.

Operator Designs Much Equipment.—Long-range operations such as one-stop transcontinental schedules are no longer dreams of the air-line operator. Plans for the operating and maintenance procedures to handle these flights are far beyond the embryo state of development. For the last two years we have had engineers on special assignments to the aircraft factories in order to gather data on future equipment; proposed specifications for engines, instruments, cabin equipment, passenger requirements, and the myriad of details that must be worked out before the ultimate equipment even reaches the drafting boards. At our LaGuardia Field base we have constructed a wooden mock-up of the Douglas DC-4, four-engine transport, lounge and buffet section with engineers and special mechanics assigned to the duty of designing all of the food and lounge equipment facilities. This type of airplane, to be put into service the latter part of 1941, must have such items as cabin equipment and ground service equipment completely projected and designed before the airplane itself goes into final production. We now have one engineer at the Douglas factory in California assigned to the duty of working out plans and designs for the hydraulic, electrical, and de-icer system test units, passenger and cargo loading ramps, and all refueling and ramp equipment, practically the redesign of all present equipment which cannot be adapted to use on airplanes of a completely new design and which must be available for use by the time the new airplanes are put into service.

The motto of American Airlines is:

Aviation in itself is not inherently dangerous, but like the sea, it is terribly unforgiving of any carelessness, incapacity or neglect.

As further indication of the thoroughness with which the transport lines operate, a bulletin of the Eastern Air Lines, Inc., is given.

Maintenance Bulletin No. 50 of the Eastern Air Lines, Inc.

Overhaul and Inspection Periods

Experience gained through numerous aircraft overhauls indicates that it is erroneous to assume that a detailed overhaul program for any aircraft at the completion of a definite period of service time can be established accurately from the standpoint of airworthiness or from an economical standpoint.

Changes in designs, alterations, materials, protective finishes, operating technique, and routine maintenance procedures greatly affect the periods between needed overhauls and the ultimate service life of aircraft components. To maintain aircraft in a state of continuous airworthiness, the most advantageous policy would incorporate major inspections at definite service periods with replacement of components at periods consistent with actual service experience; these replacements together with such repairs, refinishing, or engineering alterations as may be required to be accomplished at station, routine, terminal, and base checks or at engine change. Since major inspection requires a degree of disassembly, such repairs as may be found to be needed, engineering alterations, or refinishing of components not accessible at station, routine, terminal, and base inspections, or engine check periods would be accomplished at major inspection periods.

Periods of below peak operation during certain seasons of the year may under some conditions make it desirable to remove an aircraft from service during these periods and complete a major inspection of all its components simultaneously. In event of major damages to an aircraft, its condition may warrant disassembly for major inspection regardless of service life.

Definitions. *Overhaul.*—The term "overhaul" shall mean the disassembly of an aircraft, engine, propeller, or appliance to an extent necessary for complete inspection or check of each part thereof, the replacement, repair, adjustment, or refinish of such part or parts as are found upon inspection or check to require

replacement, repair, adjustment, or refinish and the reassembly of such aircraft, engine, propeller, or appliance.

Check.—The term "check" shall mean the procedure necessary to determine the operating conditions of a mechanism, component or part of an aircraft, engine, propeller, or appliance, by measurement or operation, or both. Represented by "C" on the following schedules.

Inspection.—The term "inspection" shall mean a visual examination to determine as far as possible from such examination, the condition of an aircraft, engine, propeller, or appliance or any component or part thereof. Represented by "I" on the following schedules.

Base Check.—"Base" checks covering all items on routine and terminal checks and additional items will be performed at Miami and Newark at periods varying from 90 to 100 hr. These checks may be performed at Washington, Atlanta, Chicago, or other stations if so assigned, and equipment and personnel are available. Because of special equipment or materials necessary, some of the items on the base checks can be performed at Miami only.

Terminal Check.—"Terminal" checks will be performed at Miami and Newark at periods varying from 40 to 50 flying hr. These checks may be performed at Washington, Atlanta, Chicago, or other stations if so assigned, and equipment and personnel are available.

Routine Check.—"Routine" checks covering specified items are made at the end of trip or at completion of several trips, the total flying time of trip or trips not exceeding 20 hr. Routine checks will normally be made at Miami, Newark, Atlanta, Chicago, Brownsville, San Antonio, and Washington. They may be performed at New Orleans, Tampa, Jacksonville, Richmond, Charleston, Memphis, and Houston, if so assigned. A routine inspection will be required if a ship will accumulate in excess of (18) flying hr. upon completion of next scheduled trip, since ship last received a routine, terminal, or base check.

Station Check.—"Station" checks cover all items reported on pilot's airplane and engine performance report (Form EAL-10) and final plane check out report (Form EAL-206). The station check is to be performed at stations where trips originate and maintenance personnel are based, provided the airplane has had a layover of 12 hr. or more and the total flying time since last check is in excess of 12 hr.

Schedule of Overhaul Periods

	Hr.
Engines, Wright GR-1820-F2B	650
Accessories, Wright GR-1820-F2B	650
Engines, Wright GR-1820-G2E	550
Accessories, Wright GR-1820-G2E	550
Wheels, brakes, and tail wheel	500
Propellers—Hamilton Standard:	
No. 23E50 hub, No. 6153A-18 blades	550
No. 3E50 hub, No. 6105A-24 blades	650
No. 3E50 hub, No. 6111-6 blades	650

	DC-3, hr.	DC-2, hr.
Instruments:		
Bank-and-turn indicator	2,750	3,250
Airspeed indicator	2,750	3,250
Pitot-static head	3,000	3,000
Compass	2,750	[illegible],250
Artificial horizon	1,500	1,800
Clocks	2,750	3,250
Altimeters	2,750	3,250
Oil pressure gages	2,750	3,250
Fuel pressure gages	2,750	3,250
L. G. pressure gages	2,750	3,250
Hydraulic pressure gages	2,750	
Rate-of-climb	2,750	3,250
Manifold pressure gages	2,750	3,250
Suction gages	2,750	3,250
Deicer pressure gage	Annual	Annual
Directional gyro	1,500	1,800
Electrical instruments	4,000	4,000
Other	4,000	

One of the inspection sheets used is shown herewith. There are three sets of these. The sheets for the Base have 166 items; the "Terminal" sheets have a few less; the "Routine" sheet has still fewer. The "Bi-base" supplement, still another sheet, has 17 items, such as changing wheel assembly, brake assembly, and other maintenance jobs.

As will be seen, either the mechanic or the inspector must sign or initial each item, most of which apply to the 2, 3, and T planes. The letters C and I are explained at the top of the sheet.

Base

E.A.L. Inspection: Douglas DC-2-3 and DST Airplanes

Date_ _Ship

All items on this form applicable to equipment installed and on type airplanes designated plus items inserted by inspector on this form and supplementary forms, which become a part of this form, are to be executed. "C" items are to be performed by mechanic and "I" items by inspector. A check mark in the "Note" column indicates special work on that particular item, which will be explained fully in blank spaces at end of group or on back of sheet.

Item no.	Operation	DC2 DC3 DST	I C	Mechanic		Note	Inspector	
				Left	Right		Left	Right
	ENGINES							
1	Remove rear cowl	23T	C					
2	Remove antidrag ring cowl	23T	C					
3	Wash engine and mount	23T	C					
4	Cylinder heads	23T	C					
5	Compression by turning engine and listening	23T	C					
6	Remove oil strainer and clean	23T	C					
7	Grease fuel pump	2	C					
8	Drain fuel sumps and strainers	23T	C					
9	Carburetor fittings and gaskets	23T	C					
10	Drain carburetor bowls	23T	C					
11	Drain oil sumps and radiators	23T	C					
12	Clean vacuum pump drain and exhaust line	23T	C					
13	All engine nuts for tightness and safety	23T	C					
14	Operation and travel of all engine controls	23T	C					
15	Valves (1st base after engine overhaul)	23T	C					
16	Cylinder base nuts (visually)	23T	C					
17	Oil in R Qts. L. Qts.	23T	C					
18	Oil drained R. Qts. L. Qts.	23T	C					
19	Engine mounts	23T	I					
20	Engine mount bolts and shocks	23T	I					
21	Exhaust ring and tail pipe	23T	I					
22	Exhaust pipes and gaskets	23T	I					
23	Intake pipes and gaskets	23T	I					
24	Oil radiator and brackets	23T	I					
25	All lines forward of firewall	23T	I					
26	Installation of all engine controls	23T	I					
27	P. & W. oil temperature regulator	3T	I					
28	Oil tank	23T	I					
29	Hydraulic gear pumps	3T	I					
30	Propeller governors	23T	I					
31	Primers connections for leaks	23T	I					
32	Cowl leather, felt and pads	23T	I					
33	Cowl for cracks and fit	23T	I					
34	Cowl supports	23T	I					
	LANDING GEAR & HYDRAULIC SYSTEM							
50	Air in L. G. and T. W. tires	23T	C					
51	L. G. and T. W. strut height	23T	C					
52	L. G. latch—lube	23T	C					
53	L. G. and T. W. fittings—lube	23T	C					
54	Tail lock mechanism—lube	23T	C					
55	Fwd. and rear bungee fittings—lube—oil	23T	C					
56	Operation of brakes	23T	C					
57	Hydraulic fluid supply reservoir	23T	C					
58	Spherical pressure tank	3T	I					

AIDS TO TERMINAL INSPECTION

Eastern Air Lines Terminal

Just as railroad terminals develop interesting and timesaving methods to facilitate maintenance of locomotives and cars, so air-line terminals devise special tools for their work. Some of these are shown herewith. In most cases they require little or no explanation. The five illustrations that

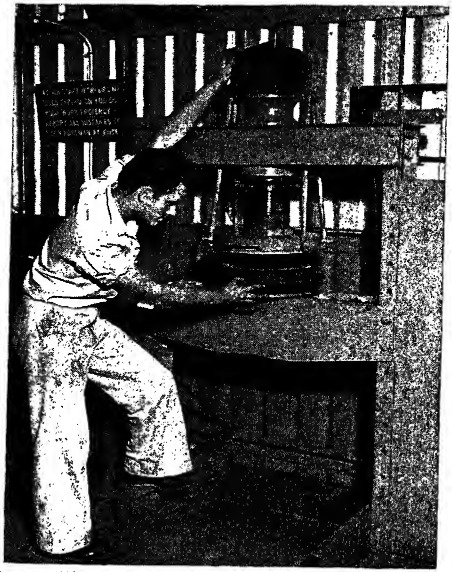


FIG. 1.—Hydraulic press to straighten brake-drum flanges.

follow immediately are by courtesy of H. G. Lesley, maintenance engineer of the Miami terminal of the Eastern Air Lines, Inc.

Brake Drums.—Figure 1 shows a hydraulic press for straightening flanges on steel brake drums. At the right of Fig. 2 is a special puller for removing cast-iron brake drums from the landing gear wheels; to the left is a special grease gun for forcing grease into the ball bearings used in the landing wheels.

Landing Gears.—In Fig. 3 is a fixture, welded up from steel angles, in which complete landing gears can be assembled. This also gives a good idea of the diameter of the balloon tires used and of the size of the parts in the landing gear as a whole.

Boilers.—Boilers for supplying hot water on transport planes must fit into limited spaces. To ensure keeping them within the specified limits, they are welded in a jig, as seen in Fig. 4. This holds the shell of the boiler

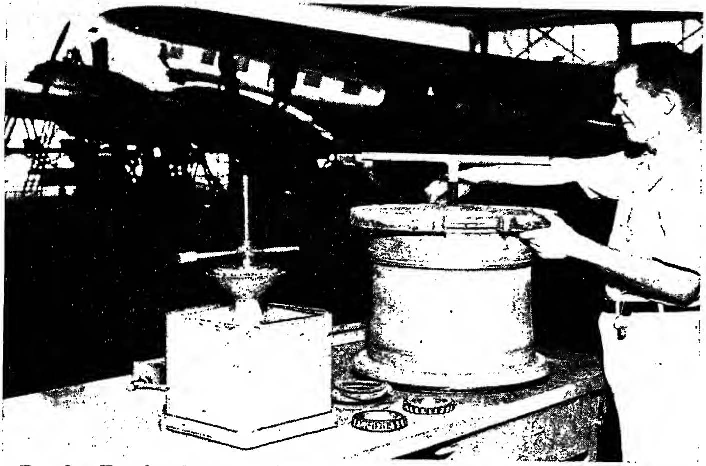


FIG. 2.—Two handy pieces of service equipment—a puller and a grease gun.

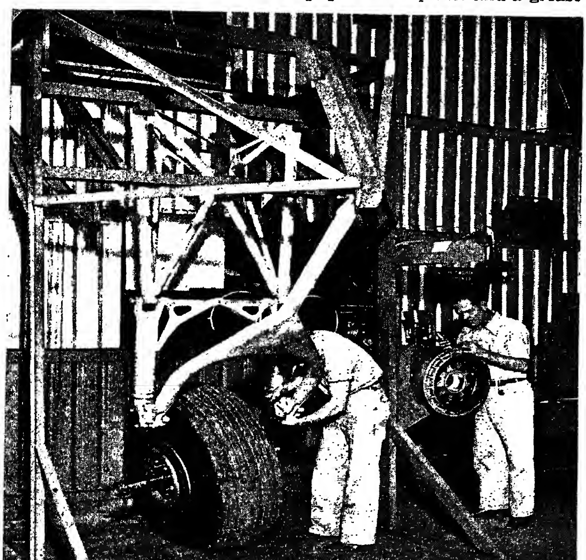


FIG. 3.—Jig used in assembling complete landing gear.

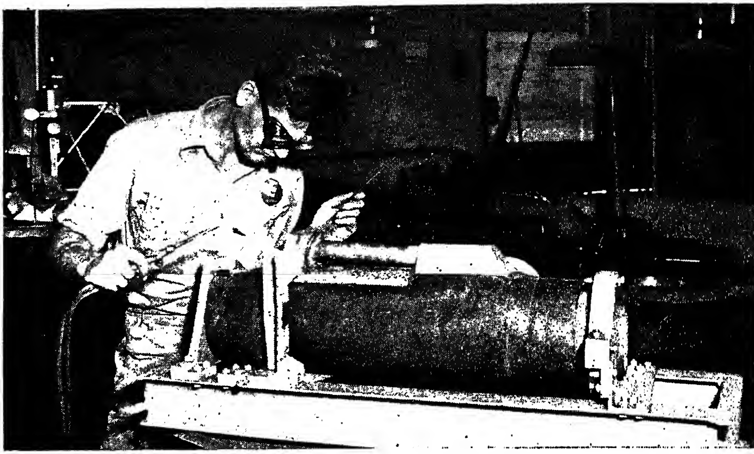


FIG. 4.—Welding a hot-water boiler.

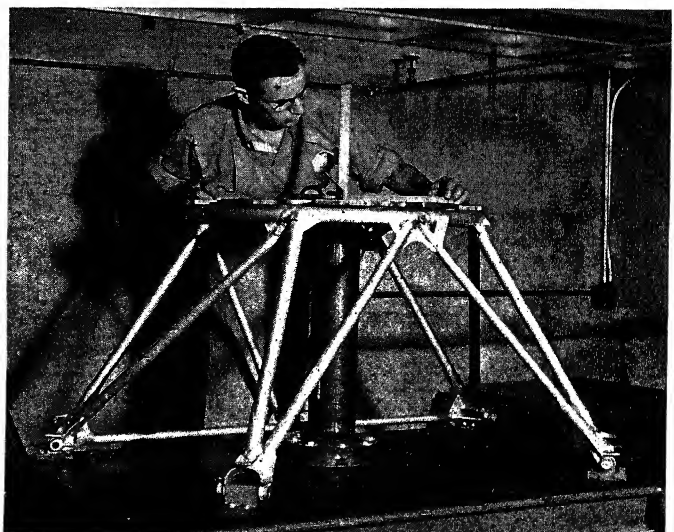


FIG. 5.—Checking alignment of an engine mount.

and the attachments in proper position while they are being welded. In this way dimension tolerances are kept at a minimum.

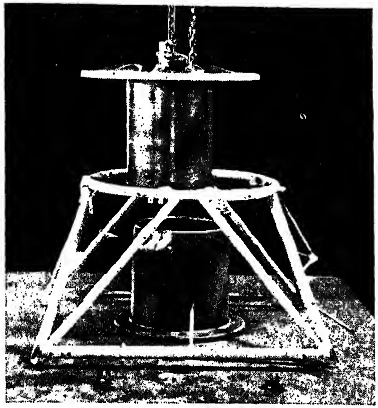


FIG. 6.—Another method of checking engine mounts. This is used at San Diego Naval Station. (*Official U.S. Navy Photograph.*)

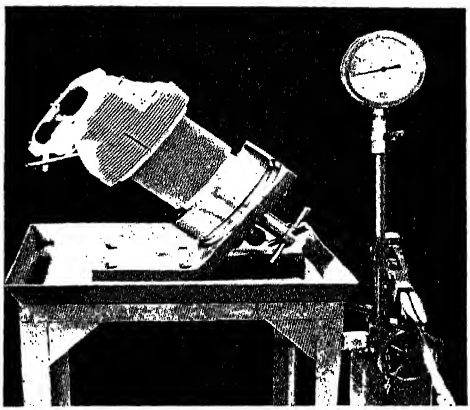


FIG. 7.—Stand for testing cylinder leakage at San Diego. (*Official U.S. Navy Photograph.*)

Engine Mounts.—Alignment of engine mounts is very important. Before they are put on a plane, they are checked for accuracy on the fixture in Fig. 5.

U.S. Navy Station, San Diego

In Fig. 6 there is a somewhat similar but more generally used centering device than that in Fig. 5. This large surface plate has numerous holes

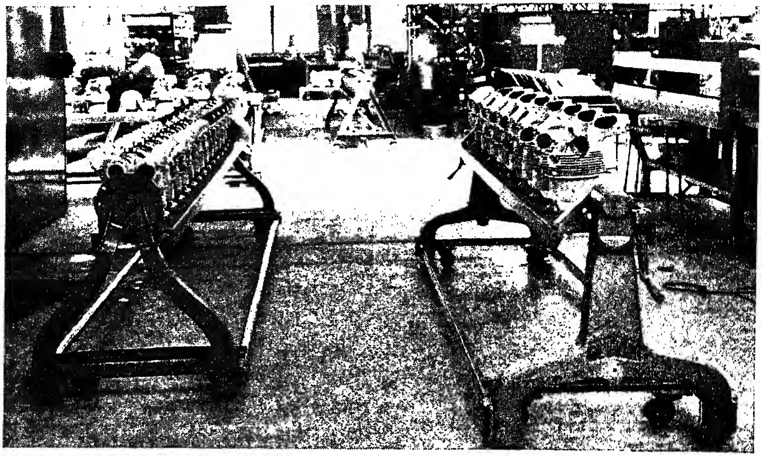


FIG. 8.—Storage stands for cylinders at San Diego. (*Official U.S. Navy Photograph.*)

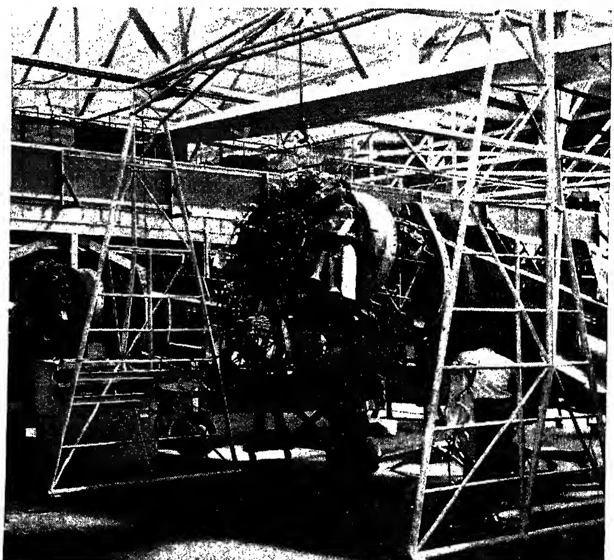


FIG. 9.—Crane for handling engines at San Diego. (*Official U.S. Navy Photograph.*)

to which can be fastened engine mounts from planes of any type in use at the San Diego station of the U.S. Navy; it handles all sizes from the training plane to the bomber. It is used in all repair and alignment work at this station.

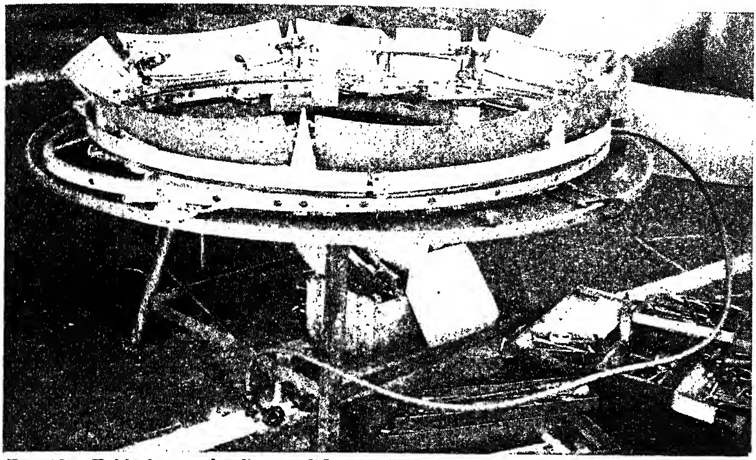


FIG. 10.—Table for overhauling cowl flaps at San Diego. (*Official U.S. Navy Photograph.*)

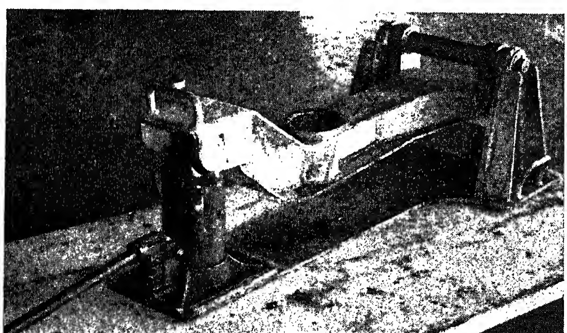


FIG. 11.—Special jack for flying boats at San Diego. (*Official U.S. Navy Photograph.*)

Cylinders.—The Navy also has many other interesting devices for facilitating its work. Figure 7 shows a convenient stand for testing cylinders for leakage. The cylinders are quickly clamped in place and pressure applied by the pump seen at the right. The gage shows when the pressure equals that to which the cylinder is subjected in service.

A convenient stand for storing cylinders safely and for moving them to any part of the shop is seen in Fig. 8. It can also be used as a workstand on which the cylinders can be turned to any angle necessary to get at the valves or for other operations. The cylinders are also assembled on these stands.

Cranes and Tables.—The size and weight of modern engines make it necessary to provide suitable means for handling them in and out of planes. In Fig. 9 is one of the lightweight, welded tubing cranes used at San Diego for this purpose. They are provided with substantial swiveling casters so as to be easily placed in the proper position. They pick the engine up at

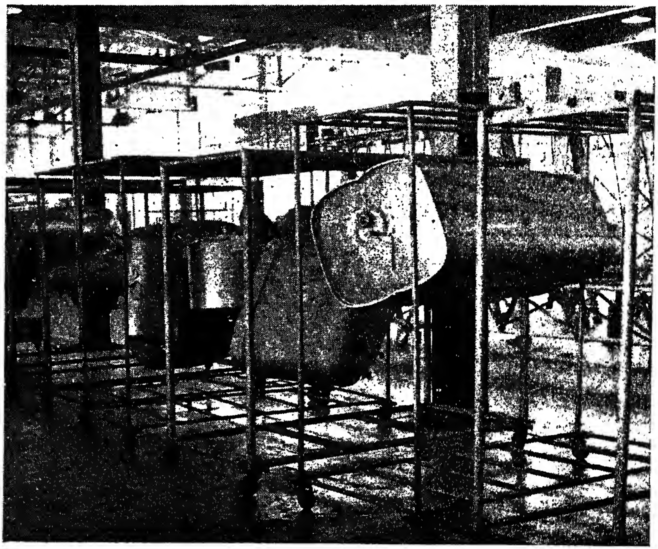


FIG. 12.—Storage racks for gas tanks at San Diego. (*Official U.S. Navy Photograph.*)

the overhaul shop and carry it to the plane, hoisting it into position by suitable drum and cable.

Engine cowl flaps and drag rings are overhauled on a special table with a rotating top, as shown in Fig. 10. This is a welded table and has compressed air connections so that the operations of the flaps, by means of the small air cylinders shown, may be thoroughly tested.

Another Navy Yard appliance is shown in Fig. 11. As can be seen this is of strong welded construction, hinged at the back end, and having a ring welded on the frame to receive a part of the boat. The jack at the left provides the lift.

Storage.—Gasoline and oil tanks are stored and handled on the racks seen in Fig. 12, which also provide transportation from the tank repair shop to the plane where they are to be installed. In the meantime they are kept safely out of the way of other material.

Other types of storage and repair trucks are seen in Figs. 13 and 14. The first shows a float in its cradle and also some wing tips on edge, in a cradle truck that holds them safely and can carry them wherever needed.

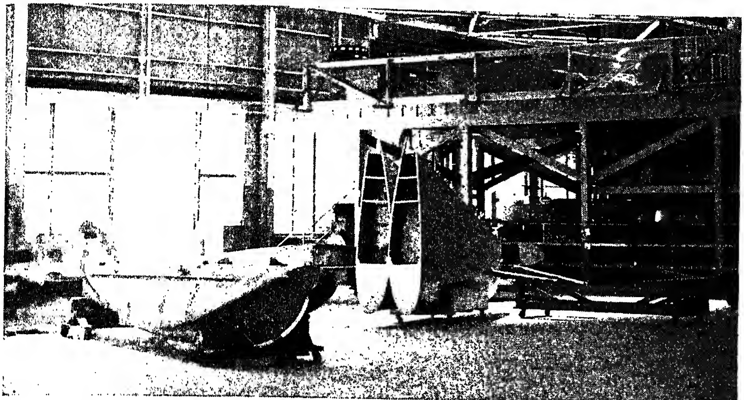


FIG. 13.—Trucks for storing floats and wing tips at San Diego. (*Official U.S. Navy Photograph.*)

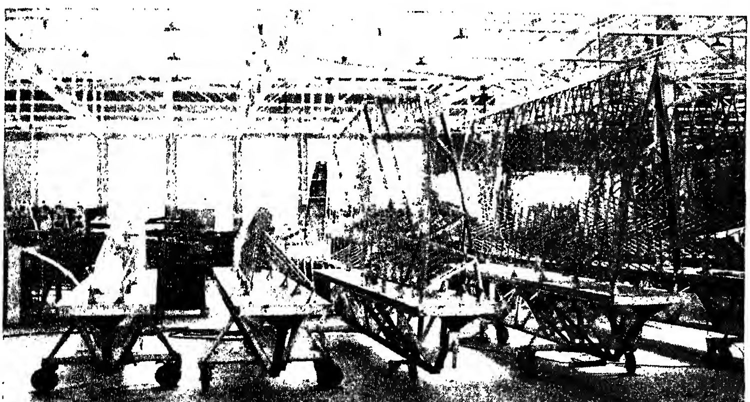


FIG. 14.—How trailing edges are handled at San Diego. (*Official U.S. Navy Photograph.*)

To the right is a similar cradle waiting to be put to use. The overhaul shop is over the finished parts storage bins shown at the right.

Handling Wing Sections.—Handling wing sections, both during their construction and afterward, requires care and special equipment. Several sections are seen in Fig. 14, with wing structures of various kinds. These

also act as jigs for building up the wings and permit the work to be moved as occasion demands.

In Fig. 15 are horses for holding wing sections, two positions being shown. All contact surfaces are covered with felt to protect the wing surfaces.

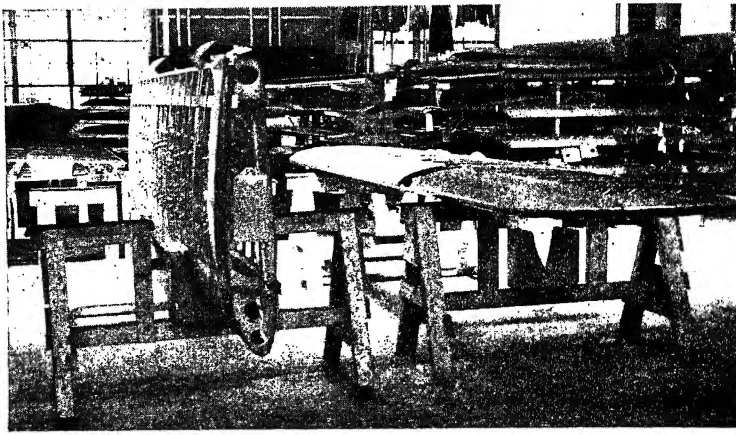


FIG. 15.—Special horses for handling wing sections at San Diego. (*Official U.S. Navy Photograph.*)

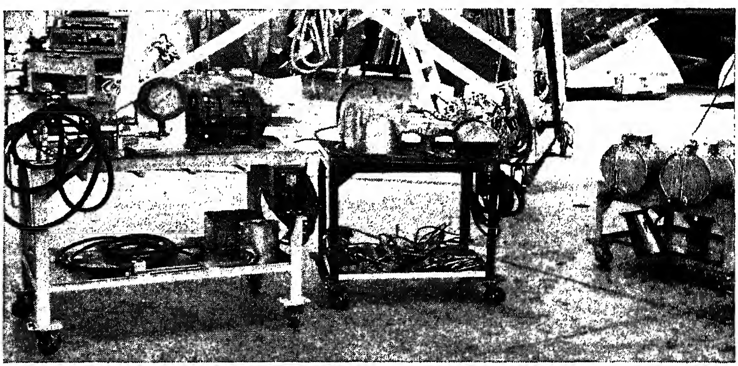


FIG. 16.—Portable test stands at San Diego. (*Official U.S. Navy Photograph.*)

Behind the wings are shelves that hold wing tips, ribs, and leading edges, until they are wanted for assembly. Protecting the surfaces of wings and leading edges is an important part of airplane maintenance.

Testing Hydraulic Equipment.—Hydraulic equipment is now an important part of all large airplanes. Its proper functioning is essential to the

safe operation of any large plane. To ensure safety, the Navy tests all hydraulic mechanisms after all overhauls. At the left of Fig. 16 is a portable test stand with all necessary equipment. In the center is another stand on casters with an electric motor and pump for flushing out the hydraulic lines on the plane. Tanks of the hydraulic fluid or oil are seen at the right; they are also portable and ensure getting the right kind of oil in the hydraulic system.

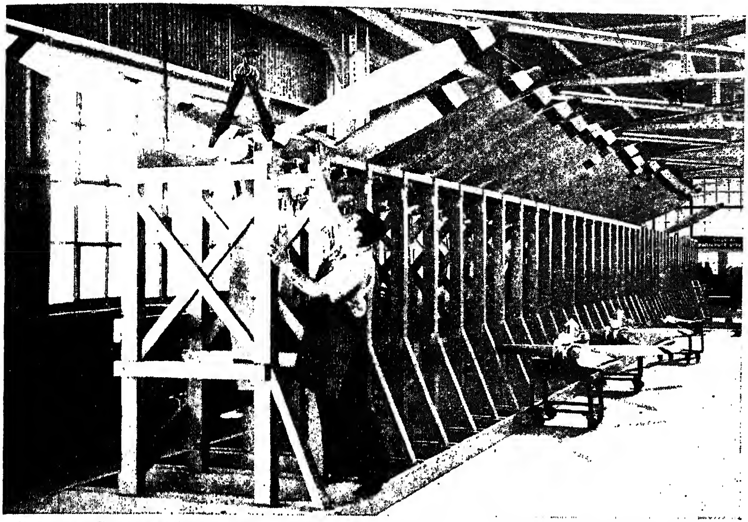


FIG. 17.—Storage of 3-bladed propellers at San Diego. *(Official U.S. Navy Photograph.)*

Storage of three-bladed propellers is seen in Fig. 17. This device keeps them safe and yet readily accessible. Two-bladed props are kept on the back of the rack on suitable pegs.

Army Airfield Methods

Maintenance mechanics are an absolute necessity in army, as well as other aviation, activities. Not only must they be dependable but they must be able to devise ways and means of meeting any demand made upon them. This includes the originating or inventing of much of the handling equipment found at airfields of the various kinds. Some of the devices shown are from the army's well-known Mitchel Field.

Crews are frequently assigned to a certain plane or planes and are responsible for their maintenance. Figure 18 shows an engine inspection by the crew assigned to it. This is a twin-engined bomber and is being inspected out of doors, as is often the case in good weather. Figure 19 shows a very convenient portable workstand or step ladder which folds into a small space and is carried in the bomber.

Hydraulic Jack.—A husky hydraulic jack that lifts 20,000 lb. is seen in Fig. 20, lifting a Douglas bomber; this was developed at the San Antonio

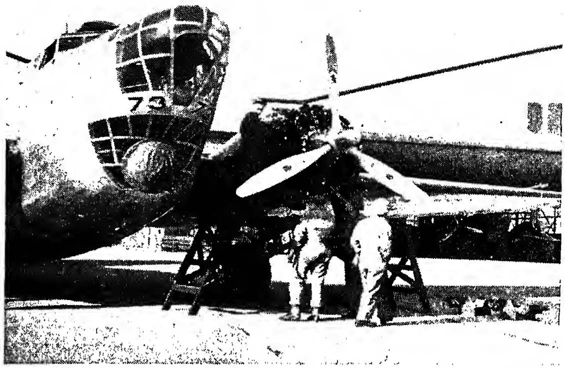


FIG. 18.—Inspection of one of the twin engines of an Army bomber.

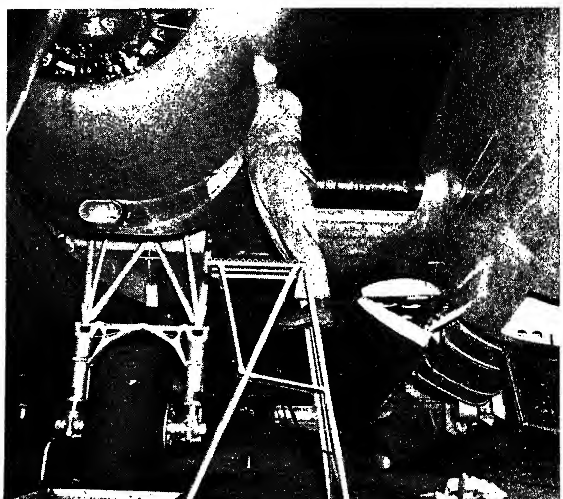


FIG. 19.—Portable, folding stand carried in plane.

airfield. In Fig. 21, a Blackhawk hydraulic jack built for the Air Corps is lifting the tail of a bombing plane. When there is no load on the jack,

the base rises from the floor enough to permit its being easily rolled about on three wheels concealed under the cone-shaped housings.

Shock struts must have the proper amount of air as well as oil. This is checked by measuring the distance between given points on the two

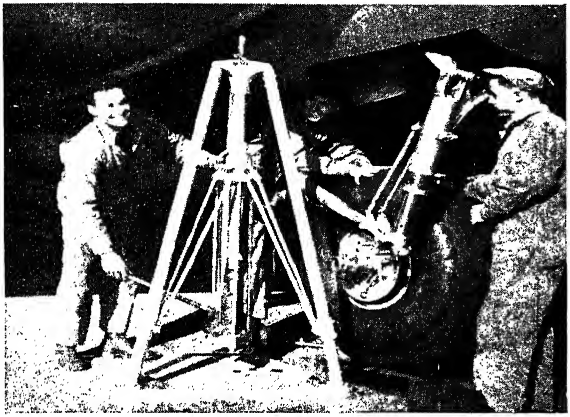


FIG. 20.—Hydraulic jack lifting a Douglas bomber.

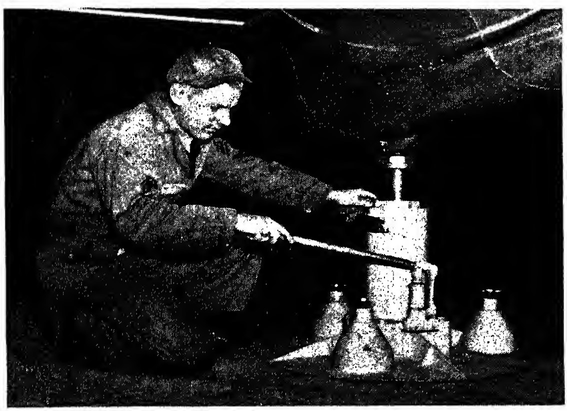


FIG. 21.—Blackhawk jack built for Army Air Corps.

members. Figure 22 shows the crew chief checking the distance with a steel rule while the man at the pump forces air into the strut. On large ships this is done with a motor-driven pump as in Fig. 23. With the booster unit on top, this compressor can deliver air at 400 lb. pressure.

Some idea of the progress in air transport of heavy materials may be had from Fig. 24 which shows an engine on its wheeled stand just as it came from the repair depot at Middletown. The entire unit is hoisted aboard an

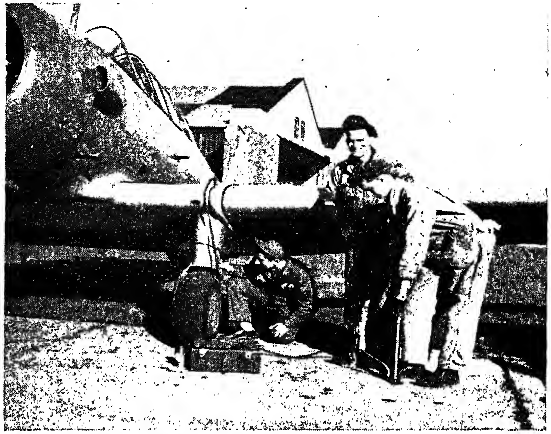


FIG. 22.—Checking travel of landing-strut cylinder.

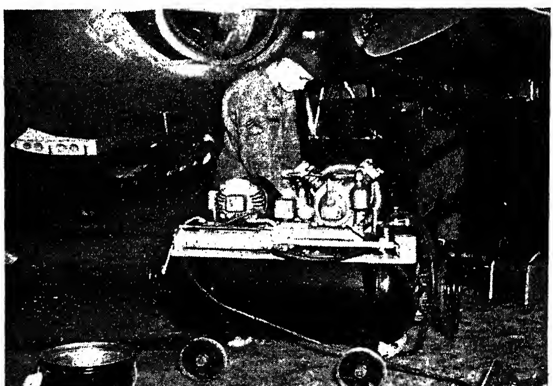


FIG. 23.—Motor-driven pump used for checking struts.

Army Douglas transport, flown to Mitchel Field, and removed, ready to be installed in a plane. After being swung out of the ship, the engine is towed to the engine shop by a tractor and put in the plane.

Portable Racks.—Three other portable racks are seen in Figs. 25 to 27. All are built up by welding steel tubing into proper assemblies to secure

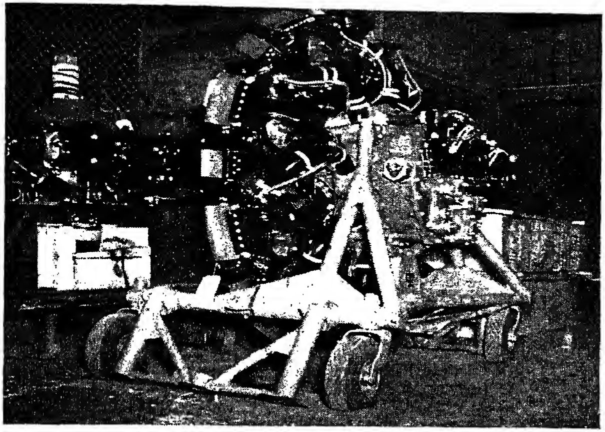


FIG. 24.—Portable stand for transporting large engines.

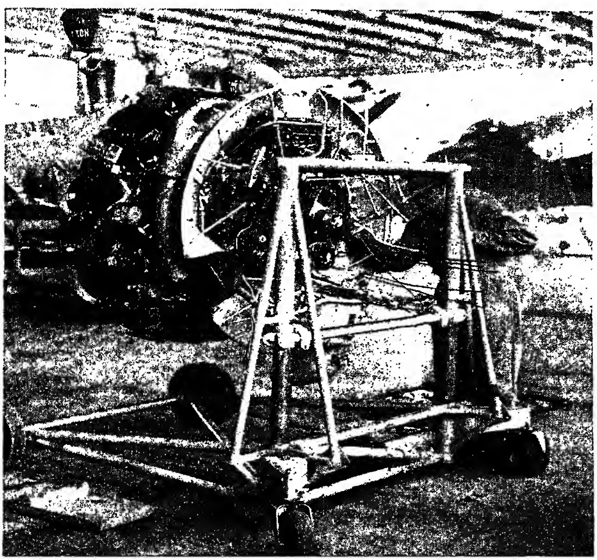


FIG. 25.—Motor repair stand. (*Official Photograph, U.S. Army Air Corps.*)

the maximum strength with the minimum weight. These are used at the Fairfield depot of the Army. Figure 25 is a stand on which the engine is mounted to assemble the accessories after the engine itself has been overhauled; it is so open that the men can get at any part of the engine with ease. When completed, the engine can be wheeled to the plane to which it belongs.

A hoist with considerable capacity, as to both height and load, is seen in Fig. 26. This was built at Fairfield for use in handling engines and

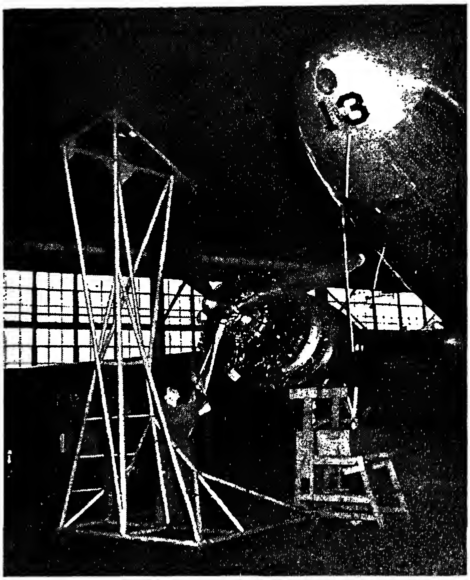


FIG. 26.—Portable engine hoist at Patterson Field. (*Official Photograph, U.S. Army Air Corps.*)

propellers; it is very light for its capacity and has a broad base to give it stability. A lighter stand, Fig. 27, equipped with a chain hoist, is found very convenient for lifting the tail of a trainer or a pursuit plane.

Training the Naval Reserve

The illustrations that follow give some idea of the extent and variety of training given at the Naval Reserve base at Floyd Bennett Field. In Fig. 28, a Grumman Duck is being checked after 30 hr. in the air by an inspection that covers 104 major items of both engine and plane. Work of this kind makes the young mechanics very familiar with both plane and engines used in the service.

In Fig. 29 is shown a Navy training plane that has had 850 hr. in the air since its last major overhaul. This is being carefully inspected by skilled

foremen and many parts will be rebuilt to put it in first-class shape before it goes into service again. All fabric covers are removed during a major overhaul and new fabric installed wherever necessary. This gives good training for handling repairs on small private planes as well as on training planes. This is shown in Fig. 30.

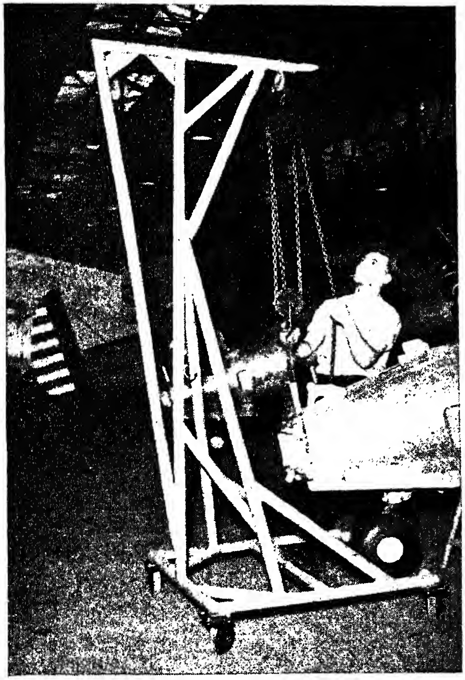


FIG. 27.—Light hoist for lifting the tails of trainers and pursuit planes. (*Official Photograph, U.S. Army Air Corps.*)

A special stand used for rehoning valve seats in the cylinders is shown in Fig. 31. A Black and Decker Vibro-centric kit is used in this work. A wooden post is mounted at the side of the stand to hold cylinders waiting for service.

Magnetos and instruments are also inspected and overhauled at the Floyd Bennett Field. In Fig. 32, a Scintilla magneto is being checked. The toolbox on the wall is supplied by Scintilla so as to have all necessary tools in a convenient place. The lid swings down so that the whole kit can be locked when not in use. A corner of the instrument shop is seen in Fig. 33, showing an altimeter-testing device. This gives air pressures that simu-

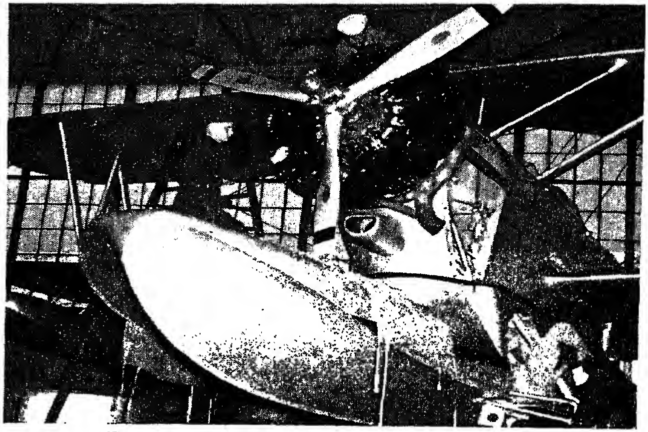


FIG. 28.—Inspection of a Grumman "Duck."

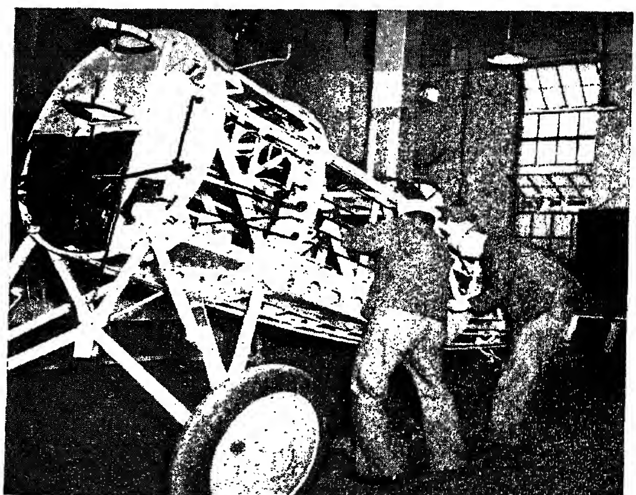


FIG. 29.—Inspection of Navy training plane after 850 hr. in the

FIG. 30.—Replacing fabric covers on overhauled training planes.

FIG. 31.—Re-honing valve seats at engine overhaul.

FIG. 32.—Inspecting magnetos at Floyd Bennett field.

FIG. 33.—Device for checking altimeters.

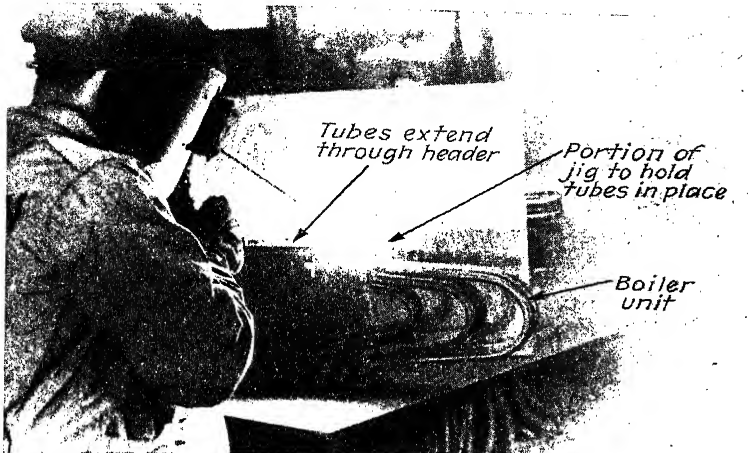


FIG. 34.—Welding heating boilers at American Airlines' Chicago Terminal.

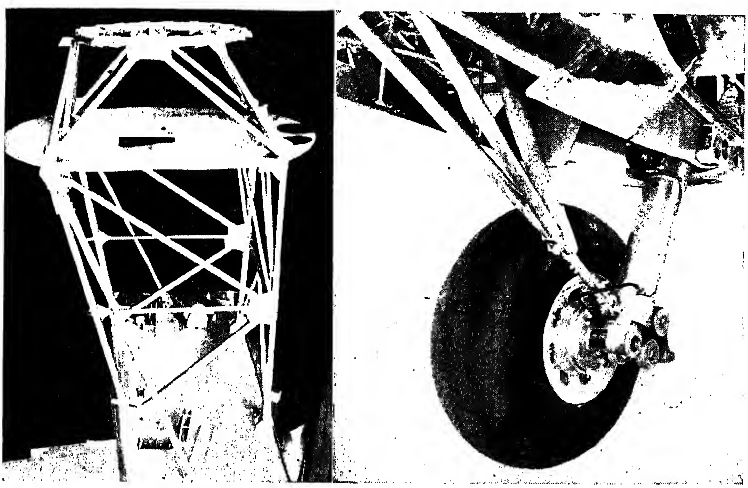


FIG. 35.—Additional parts repaired by electric welding. (*Courtesy of The Lincoln Electric Company.*)

late different altitudes at which the instrument must be used. Overhauled instruments must check with an altimeter that is known to be correct.

Welding in Aircraft Maintenance

A striking example of the advantage of electric welding in aircraft maintenance is given by American Airlines, Chicago Terminal in handling the heating boilers used in their planes. With their previous methods of welding boilers, they had a failure record of nearly 10 per cent per day at a cost of approximately $57,000 a year on only 30 planes.

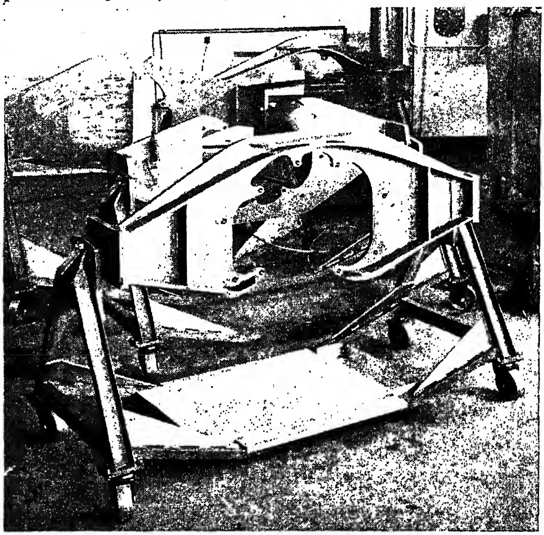


FIG. 36.—Fixture for holding engine mounts during welding. *(Courtesy of The Lincoln Electric Company.)*

With a Lincoln 150-amp. machine, a method of welding was worked out which uses the jig and the technique shown in Fig. 34 which has proved most satisfactory. With a stainless-steel arc welding electrode and the jig referred to, the first boiler was welded in less than 1 hr.—one-eighth of the time formerly required. This method has greatly reduced the cost of the boilers, which now have a service life of 450 hr., after which they are destroyed and replaced with new ones.

The Lincoln Electric Co. has developed a welding electrode especially for aircraft work, known as "Planeweld." It is particularly designed for welding S.A.E.-4130 and X-4130 chrome-molybdenum steels, both of which are widely used in aircraft work. It is used in fuselage, tail supports, landing gears, as in Fig. 35, engine mounts, and other parts.

In addition to aircraft parts, welding is used in making such fixtures as engine overhaul stands, as shown in Fig. 36. These are used for engines up to 1,500 hp.

Oxyacetylene Welding.—One of the pioneers in oxyacetylene welding is the Linde Air Products Co., a division of the Union Carbide and Carbon Co. They have developed methods of welding tubes and other aircraft structures that are used in some of the plants producing planes in quantity. A paper prepared by Hanford Eckman, production manager of the Piper

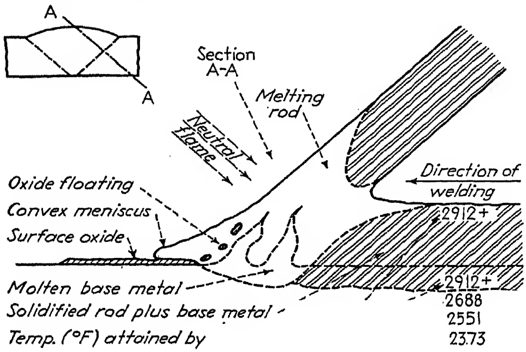


FIG. 37.—Diagram of welding with a neutral flame.

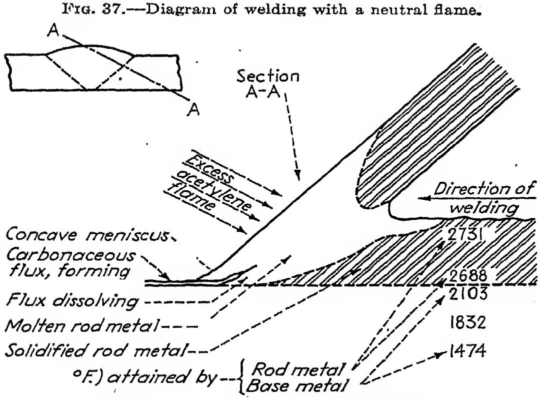


FIG. 38.—Flame diagram with excess acetylene.

Aircraft Corp., shows two types of welding flame and gives their characteristics. Figure 37 illustrates a neutral flame and shows the temperatures at different points. A study of it reveals what is happening at the various parts of the weld.

In Fig. 38 is a flame with excess acetylene, which is now recommended as providing a faster method and one that welds at a lower temperature. The difference in heat is shown by comparing the values in Figs. 37 and 38, at various points. The increased speed of welding also lessens the distortion.

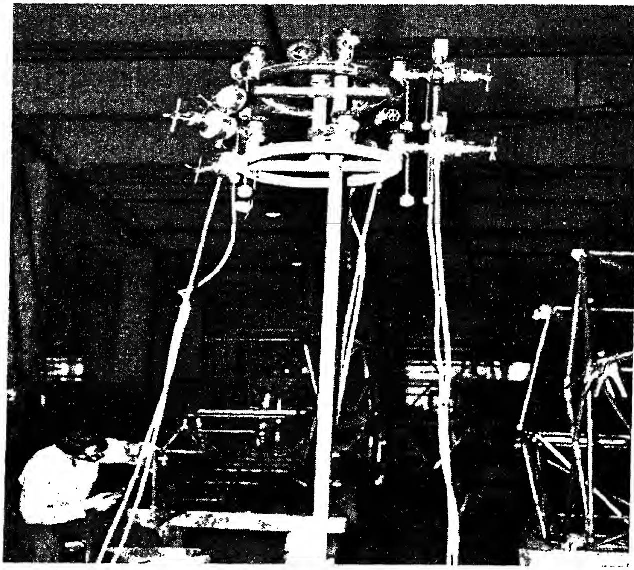


FIG. 39.—Stand to hold gas lines out of the welder's way.

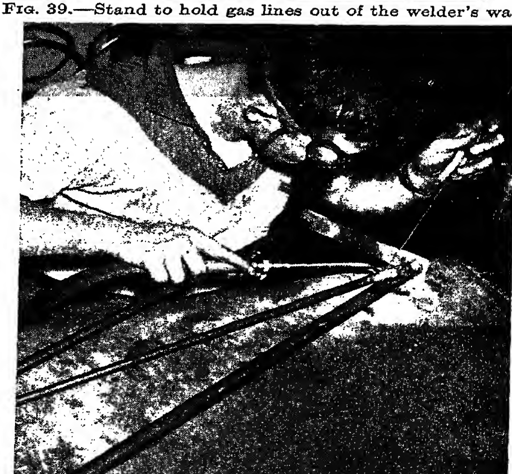


FIG. 40.—Welding a compression strut.

A method of conserving floor space is seen in Fig. 39 where oxygen and acetylene are supplied through drop rings that come down from the ceiling and leave the floor clear of hose lines except as they are being used.

In Fig. 40 a compression strut is being welded on a bench protected by a steel plate. Figure 41 shows a stainless-steel muffler in its final stages.

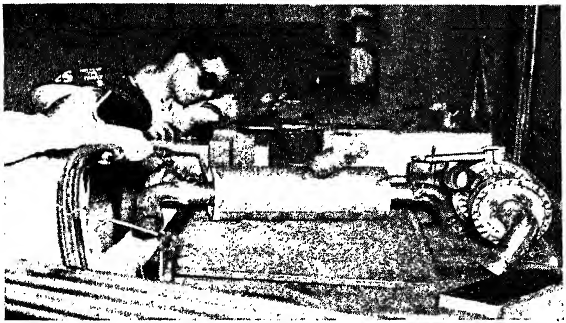


FIG. 41.—Welding a stainless steel muffler.

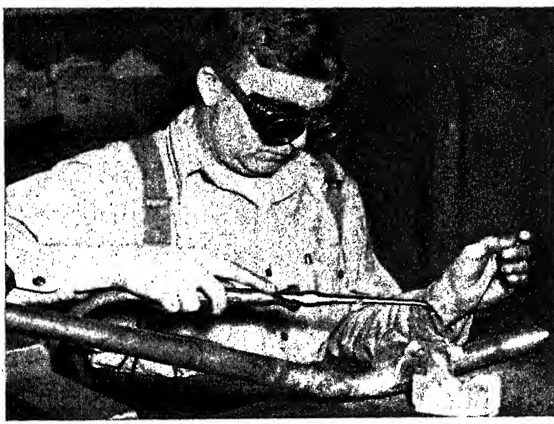


FIG. 42.—At work on an axle job.

Jobs of this kind apply equally to maintenance and to manufacture. A landing gear axle job is being done in Fig. 42.

In both types of welding, it is necessary to have experienced men to ensure welds that are both safe and satisfactory. There are good welding schools where both types are taught. As in all other aircraft work, the utmost care and integrity are essential. No "good enough" welds can be tolerated; each one must be as nearly perfect as it can be made.

SECTION XX

S.A.E. AIRCRAFT STANDARDS

Although this volume was not written for designers of aircraft, references have been made to standards adopted by the Society of Automotive Engineers for propellers and for some other parts. Accordingly, it seems best to include some of the standards[1] that have been adopted so that the reader may know just what is meant whenever they are mentioned.

Included are the dimensional standards for units, parts, and finished constructional materials used in aircraft, their component assemblies, and in accessory equipment; also descriptive references to the S.A.E. Aeronautical Material Specifications and to the S.A.E. Aircraft Engine Testing Code.

AIRCRAFT ENGINE TESTING CODE

The S.A.E. Aircraft Engine Testing Code and Forms, similar in purpose to the S.A.E. gasoline and diesel engine forms, describe the routine practices generally followed in determining the operating characteristics of aircraft engines and have been compiled as a guide for aircraft engine testing. However, divergence from the practices described will occasionally be found necessary in the course of laboratory investigation of specific problems.

The testing code and forms conform to the specifications and regulations of the Federal air services governing aircraft engine testing, but any testing conducted for the approval of the Army, Navy, or C.A.A. must be governed by Army-Navy specifications or C.A.A. regulations. Copies of current issues of these specifications and regulations may be obtained directly from the

U.S. Army Air Corps, Chief of Material Division, Wright Field, Dayton, Ohio.
U.S. Navy, Bureau of Supplies and Accounts, Washington, D.C.
C.A.A., Chief Aircraft Airworthiness Section, Washington, D. C.

The forms were prepared to meet the need for standardized mechanical information and log sheets and a set of curve sheets with accompanying correction data, for use in recording engine tests and for reference purposes between engine manufacturers and purchasers.

The complete code consists of two parts, the aircraft engine test procedure and the aircraft engine testing forms, each being subdivided into sections as follows:

Section I
Determination of Power Output Directions

Cradle dynamometer (formula)
Torque stand (formula)
Rigid stand (discussion and formula)

Section II
Determination of Engine Operating Characteristics

Manifold pressure curves (description):
  Constant r.p.m. curves (directions)
  Constant throttle curves (directions)

[1] Reprinted by permission of S.A.E.

Mixture control curves (description):
- Constant power curves (directions)
- Constant throttle curves (directions)

Altitude power curves (no attempt is made to give directions on simulated altitude testing or equipment)
Full throttle curves (description and directions)
Full rich propeller load curve (description and directions)
Constant b.m.e.p.—Maximum economy curves (description and directions)

Section III
Test Equipment Calibration

Test propeller calibration (directions and formulas)
Torque stand calibration (directions and formulas)
Calibration of test apparatus and instruments

Section IV
Measurements and Computations

Full throttle corrected horsepower
Part throttle corrected horsepower
Actual horsepower from corrected values (rigid stand)
Brake mean effective pressure
Fuel consumption
Barometric pressure
Atmospheric vapor pressure
Fuel temperature
Fuel pressure
Cylinder head temperatures
Oil temperatures
Oil flow
Heat rejection to oil
Oil consumption
Manifold pressure
Scoop pressure
Carburetor air temperature
Engine oil pressure
Scavenge oil pressure
Crankcase pressure
R.p.m.

Section V
Definitions

Normal rated speed
Normal rated power
Take-off speed
Take-off power
Normal rated altitude
Altitude horsepower
Rated manifold pressure
Take-off manifold pressure
A sea level engine
An altitude engine
Actual or observed brake horsepower
Standard conditions at sea level
Scoop pressure
Specific fuel consumption
Specific oil consumption
Mixture settings:
- Full rich
- Best power
- Best setting
- Best economy

Propeller load horsepower
Take-off b.m.e.p.
Rated b.m.e.p.

Aircraft Engine Testing Forms

The testing forms accompanying the code consist of the following sections:

Section A—Description of forms and acceptance test directions for engines in production
Section B—Mechanical information
Section C—Log sheet
Section D—Table of Temperature Corrections for Mercury Columns—*D*-1
Atmospheric Vapor Pressure Chart—*D*-2
Full Throttle Horsepower Correction Chart (29.92 in. Hg, zero vapor pressure and 60°F. temperature)—*D*-3
Horsepower Correction Factors for Carburetor Air Temperature.—*D*-4
Manifold Pressure vs. Horsepower Curves—*D*-5
Mixture Control Curves—*D*-6
Sea Level Horsepower vs. Manifold Pressure and Altitude Performance Curve—*D*-7

The code and forms are published separately from the S.A.E. Handbook in an 8½ × 11 in. booklet because the forms have been prepared for use as original records and range in size from 8½ × 11 to about 11 × 24 in. The complete booklet or the individual sheets of the code and forms may be obtained from the society at the prices indicated in the Price Schedule for S.A.E. Standards Publications in the front colored section of this S.A.E. Handbook.

Aeronautical Material Specifications

Table 1.—Aeronautical Material Specifications

Processes

No.	
2400.	Plating, cadmium
2470.	Protective treatments, aluminum alloys
2475.	Protective treatments, magnesium alloys
2503.	Black finishing, low baking
2510.	Engine gray finishing, low baking

Nonmetallics

No.	
3110.	Zinc chromate primer
3120.	Black enamel
3125.	Engine gray enamel
3180.	Toluol thinner
3220.	Synthetic rubber
3232.	Gasket, oil resistant, 300°F.
3410.	Flux, brazing, silver

Nonferrous

Aluminum and Aluminum Alloys

No.		
4000.	Sheet, aluminum	Annealed
4003.	Sheet, aluminum	3S½ H
4015.	Sheet, alloy (magnesium, chromium)	52SO
4016.	Sheet, alloy (magnesium, chromium)	52S¼ H
4030.	Sheet, alloy (copper, manganese, magnesium)	17SO
4032.	Sheet alloy (copper, manganese, magnesium)	17ST
4118.	Bars, alloy (copper, manganese, magnesium)	17ST
4125.	Forgings, alloy (silicon, magnesium, chromium)	A51ST
4130.	Forgings, alloy (copper, silicon, manganese	25ST
4135.	Forgings, alloy (copper, silicon, manganese, magnesium)	14ST
4145.	Forgings, alloy (copper, silicon, magnesium, nickel)	32ST
4290.	Die castings. alloy (silicon)	13

Magnesium Alloys
(Alloys of aluminum, zinc, manganese)

No.		
4350.	Wrought	
4360.	Forgings	
4370.	Sheet	Annealed
4420.	Castings	As cast
4422.	Castings	Solution
4424.	Castings	Precipitated
4490.	Die castings	As cast

Copper and Copper Alloys

No.		
4500.	Sheet, copper	Annealed
4505.	Sheet, brass	Annealed
4510.	Strip, phosphor bronze	Spring
4520.	Strip, bronze	Bushings
4610.	Rods or bars, free cutting brass	Half hard
4625.	Rods, bars, phosphor bronze	Hard
4630.	Rods, bars, aluminum bronze	Hard
4650.	Bars, forgings, beryllium bronze	Solution
4720.	Spring wire, bronze	
4750.	Solder, tin lead	
4755.	Solder, lead silver	
4770.	Solder, silver	
4800.	Bearings, babbitt	
4820.	Bearings, copper lead	Steel back
4822.	Bearings, copper lead tin	Steel back
4840.	Bearings, copper lead tin	Castings
4845.	Castings, bronze 10% tin	As cast
4860.	Castings, manganese bronze	As cast

Table 1.—Aeronautical Material Specifications (*Continued*)

Carbon and Corrosion-resistant Steels

Carbon

No.		
5010.	Bars, screw stock	S.A.E. X1112
5022.	Bars, forgings, 1.3 manganese (free cutting)	S.A.E. X
5024.	Bars, forgings, 1.5 manganese (free cutting)	S.A.E.
5040.	Sheet, deep drawing (annealed)	
5042.	Sheet, low carbon (half hard)	S.A.E. 1010
5050.	Tubing, low carbon (annealed)	S.A.E. 1015
5060.	Bars, forgings, low carbon	S.A.E. 1015
5110.	Music wire, commercial	S.A.E. 1080
5112.	Music wire, best quality	S.A.E. 1090
5122.	Sheet, high carbon (hard)	S.A.E. 1095

Corrosion Resistant

No.		
5510.	Sheet, annealed (18 chromium, 8 nickel)	Weldable
5516.	Sheet, annealed (18 chromium, 8 nickel)	Cold rolled
5519.	Sheet, spring (18 chromium, 8 nickel)	Cold rolled
5540.	Sheet, annealed (nickel, chromium, iron)	
5570.	Tubing, annealed (18 chromium, 8 nickel)	Weldable
5580.	Tubing, alloy (nickel, chromium, iron)	
5610.	Bars, forgings (13 chromium)	Free machining
5615.	Bars, forgings (13 chromium, low carbon)	
5630.	Bars, forgings (17 chromium, 1.0 carbon)	
5640.	Bars, forgings (18 chromium, 8 nickel)	Free machining
5645.	Bars, forgings (18 chromium, 8 nickel)	Weldable
5680.	Welding wire (18 chromium, 8 nickel)	
5685.	Wire, annealed (18 chromium, 8 nickel)	
5688.	Wire, spring (18 chromium, 8 nickel)	
5690.	Wire, screen (18 chromium, 8 nickel)	

Low Alloy Steels

No.		S.A.E.
6240.	Bars, forgings (5 nickel)	Carburizing, 2515
6242.	Bars, forgings (5 nickel)	Carburizing, 2515
6250.	Bars, forgings (3.5 nickel, 1.5 chromium)	Carburizing, 3312
	Bars, forgings (3.5 nickel, 1.5 chromium)	Carburizing, 3312
[illegible]	[illegible] 0.25 molybdenum)	Carburizing, 4615
[illegible]	[illegible] (1.8 nickel, 0.25 molybdenum)	[illegible], 4615
6294.	Bars, forgings (1.8 nickel, 0.25 molybdenum)	[illegible]g, 4620
6310.	Bars, forgings (1.8 nickel, 0.25 molybdenum)	0.33–0.38 carbon, 4640
6312.	Bars, forgings (1.8 nickel, 0.25 molybdenum)	0.40–0.45 carbon, 4640
6315.	Bars, forgings (1.8 nickel, 0.25 molybdenum)	105,000 tensile, 4640
6317.	Bars, forgings (1.8 nickel, 0.25 molybdenum)	125,000 tensile, 4640
6330.	Bars, forgings (1.25 nickel, 0.6 chromium)	0.35–0.40 carbon, 3135
	Bars, forgings (1.25 nickel, 0.6 chromium)	0.40–0.45 carbon, 3140
	Bars, forgings (1.25 nickel, 0.6 chromium)	105,000 tensile, 3140
6337.	Bars, forgings (1.25 nickel, 0.6 chromium)	125,000 tensile, 3140
6352.	Sheet, annealed (0.8 chromium, 0.2 molybdenum)	0.30–0.35 carbon, X4130
6360.	Tubing, normal (0.8 chromium, 0.2 molybdenum)	0.30–0.35 carbon, X4130
6370.	Bars, forgings (0.8 chromium, 0.2 molybdenum)	0.30–0.35 carbon, X4130
6380.	Bars, forgings (1 chromium, 0.2 molybdenum)	0.35–0.42 carbon, 4140
6382.	Bars, forgings (1 chromium, 0.2 molybdenum)	0.38–0.46 carbon, 4140
6412.	Bars, forgings (nickel, chromium, molybdenum)	0.35–0.40 carbon, X4340
6415.	Bars, forgings (nickel, chromium, molybdenum)	0.35–0.45 carbon, X4340
6440.	Bars, forgings (1.35 chromium)	52100
6455.	Sheet, annealed (chromium, vanadium)	Spring, 6150
6470.	Bars, forgings (chromium, molybdenum, aluminum)	Nitriding

Accessories, Fabricated Parts, and Assemblies

No.		
7210.	Cotter pins (18 chromium, 8 nickel)	
7220.	Rivets (aluminum)	2S
7222.	Rivets (aluminum alloy)	A17ST
7225.	Rivets, annealed (steel)	
7228.	Rivets (18 chromium, 8 nickel)	
7240.	Lock washers	

Table 2.—Propeller Hubs
(See Fig. 1)

Blade no.	1	1	1 1/2	2	1	1 1/2	2	2
Hub no.	20	30	30	30	30	40	40	50
A* +0.003 −0.000	3.878	3.878	4.190	4.503	3.878	4.190	4.503	4.503
B* +0.002 −0.000	4.247	4.247	4.622	4.997	4.247	4.622	4.997	4.997
C +0.010 −0.000	3.437	3.437	3.750	3.937	3.437	3.750	3.937	3.937
D +0.002 −0.000	0.875	0.875	1.062	1.250	0.875	1.062	1.250	1.250
E	13/16	13/16	15/16	1 1/16	13/16	15/16	1 1/16	1 1/16
F†	2.375	2.375	2.500	2.812	2.750	2.937	3.187	3.500
G	3 3/4	3 3/4	4 3/16	4 5/8	3 3/4	4 3/16	4 5/8	4 5/8
H +0.000	3.125	3.187	3.187	3.187	3.875	3.875	3.875	4.5625
J +0.000 −0.005	2.875	3.187	3.187	3.187	3.625	3.625	3.625	4.625
K	5 1/4	5 19/32	5 19/32	5 19/32	5 1/4	5 1/4	5 1/4	5 13/16
K (Ext'd.)	6 1/4	6 21/32	6 21/32	6 21/32	6 19/32	6 19/32	6 19/32	6 25/32
L	4	4 3/8	4 3/8	4 3/8	4	4	4	4 11/32
L (Ext'd.)	5 21/32	6 3/32	6 3/32	6 3/32	6	6	6	6 1/8
M	21/32	21/32	21/32	21/32	21/32	21/32	21/32	13/16
N	2 5/8	2 13/16	3 1/16	3 1/8	2 15/16	2 13/16	3	3
P	4 1/4	4 1/4	4 5/8	5	4 1/4	4 5/8	5	5
Q	1 1/2	1 1/2	1 5/8	1 5/8	1 1/2	1 5/8	1 5/8	1 5/8
R +0.005 −0.002	2.383	2.633	2.633	2.633	3.133	3.133	3.133	3.812
S +0.005 −0.002	2.164	2.414	2.414	2.414	2.881	2.881	2.881	3.562
T ±0.001	0.233	0.259	0.259	0.259	0.306	0.306	0.306	0.377
X	1 3/16	1 3/16	1 3/16	1 3/16	1 3/16	1 3/16	1 3/16	1 1/4
X (Ext'd.)	2 3/16	2 1/4	2 1/4	2 1/4	2 17/32	2 17/32	2 17/32	2 5/16
Y	2 13/32	2 21/32	2 21/32	2 21/32	3 5/32	3 5/32	3 5/32	3 27/32

* The center line of A and B shall lie within 0.002 in. of a plane perpendicular to the crankshaft bore center line. The center lines of A and B shall come within 0.002 in. of intersecting the crankshaft bore center line. The limits on the 90-deg. dimension is ±0 deg. to 1 min. The A and B bores shall be concentric with each other within 0.002 in. The hole U may be omitted at the discretion of the manufacturer.

† Shoulders located by F must be equidistant from center line of hub within 0.002 in. for perfect balance. Finish tolerances are ±0.010 in. unless otherwise specified.

Table 3.—Engine Nose Dimensions
(See Fig. 3, page 724)

S.A.E. shaft no.	A ±0.030	B ±0.001	C	D max.	E	F ±0.015	G	H	J
20	8.218	4.998	4 3/4	4 1/4	1/4	7.875	1/16	5/16	3/16
30	8.218	4.998	4 3/4	4 1/4	1/4	8.243	1/16	5/16	3/16
40	8.078	6.248	5 7/8	4 3/4	1/8	7.906	1/16	3/8	3/16
50	8.968	7.248	6 13/16	6	11/32	8.562	1/8	3/8	1/4

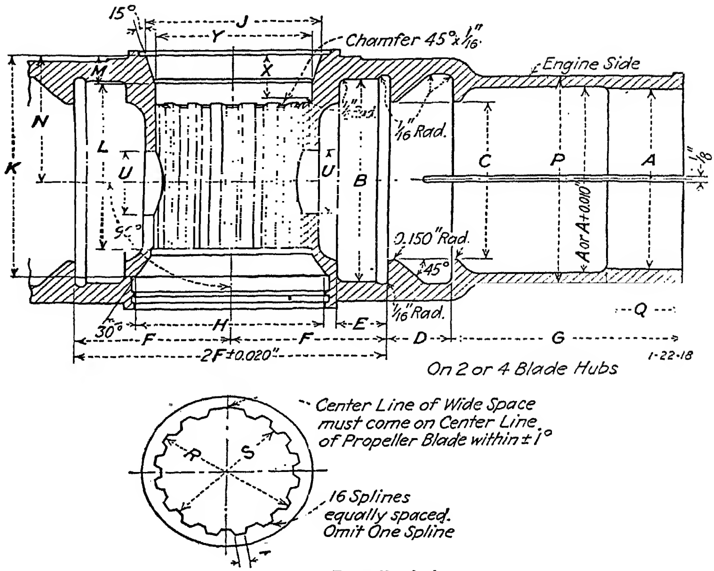


Fig. 1.—Propeller hub.

Table 4.—Hub Front Cone
(See Fig. 2)

S.A.E. shaft no.	A ± 0.0005	B $+0.005$ -0.000	C	D	E	F	G
10	1.6875	2.750	$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{9}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
20	2.0625	3.125	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{9}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
30	2.3125	3.250	$2\frac{11}{16}$	3	$2\frac{9}{32}$	$2\frac{5}{64}$	$\frac{1}{2}$
40	2.8125	3.875	$3\frac{1}{4}$	$3\frac{9}{16}$	$2\frac{9}{32}$	$1\frac{3}{32}$	$1\frac{7}{32}$
50	3.5000	4.5625	$3\frac{15}{16}$	$4\frac{1}{4}$	1	$\frac{7}{16}$	$\frac{9}{16}$

The taper and bore of both the front and rear cones are to be concentric within 0.001 in. total indicator reading, and the large diameter face of the front and rear cones is to be square with the inside diameter or bore within 0.002 in. on the indicator.

The threaded end face of the retaining nut must be square with the threads within 0.002 in. full indicator reading.

Rear cone No. 50A is primarily intended for use with standard adjustable pitch propeller hubs with or without standard spacers, depending on the shaft and hub lengths. It may be used with adjustable or controllable pitch rear extension hubs without a spacer. This cone is also intended for use with adjustable or controllable pitch propeller hubs having a rear extension cone

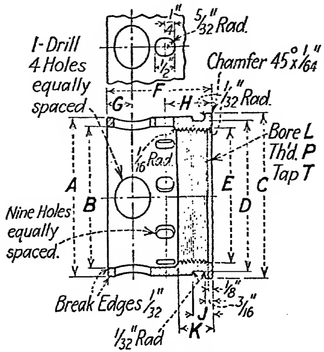


FIG. 4.—Retaining nut.

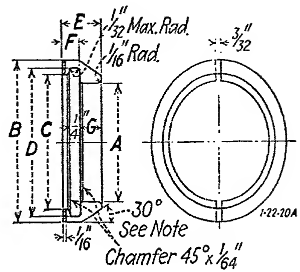


FIG. 2.—Hub front cone. *Note:* To fit angle 30 deg. ± 15 sec.

Table 5.—Hub Retaining Nut
(See Fig. 4)

S.A.E. shaft no.	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L* −0.000	*P* −0.0000	*T*
20	2 19/32	2 1/8	2 11/16	2 7/16	2 3/32	2 11/16	1 1/16	1 3/16	57/64	7/16	29/32	1.976 + 0.006	2.008 + 0.0034	2 1/16-12
30	2 3/4	2 11/32	2 15/16	2 19/32	2 11/32	2 9/16	1 9/32	1 5/32	57/64	7/16	7/8	2.229 + 0.005	2.258 + 0.0034	2 5/16-12
40	3 11/32	2 15/16	3 1/2	3 3/16	2 27/32	2 9/16	1 9/32	1 5/32	57/64	1 5/32	7/8	2.727 + 0.006	2.758 + 0.0034	2 13/16-12
50	3 7/8	3 15/32	4 3/16	.....	3 17/32	2 7/8	2 7/32	1	1 1/32	....	23/32	3.352 + 0.006	3.383 + 0.0037	3 7/16-12
50A	3 7/8	3 15/32	4 3/16	.....	3 17/32	3 3/8	2 7/32	1 7/16	1 1/32	....	1 5/32	3.352 + 0.006	3.383 + 0.0037	3 7/16-12

Aircraft—Spline Type

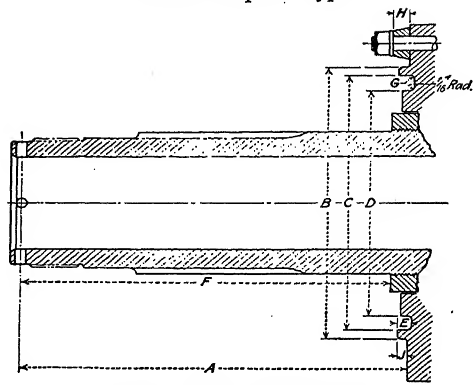
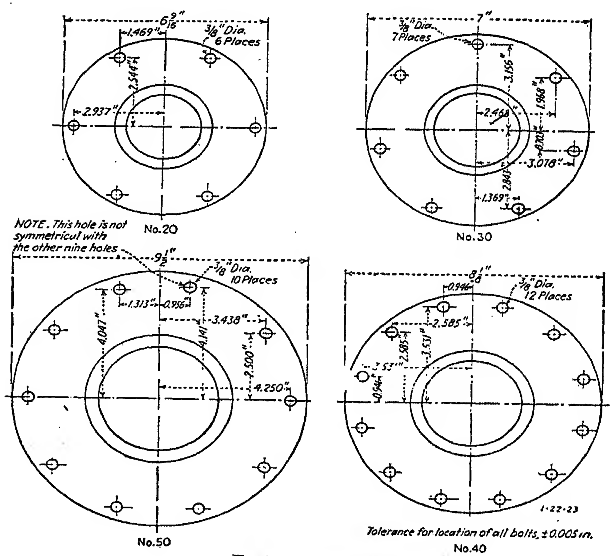


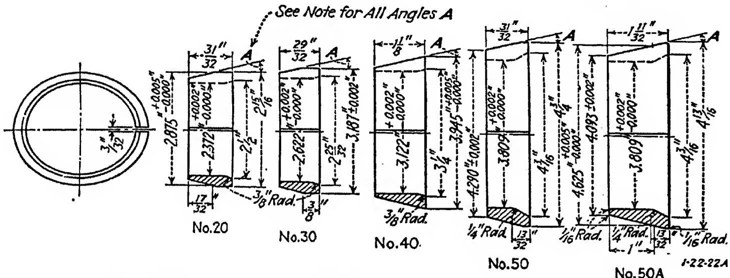
FIG. 3.—Engine nose shaft end.



Engine nose plates.

seat without spacer, and for standard adjustable pitch propeller hubs having the rear cone seat extended inward with a spacer.

The bearing contact area on the taper cone seat shall be evenly distributed and shall cover not less than 75 per cent of the design bearing area when



Hub rear cones. *Note:* Angle *A* to fit gage angle 15 deg. ± 15 sec.

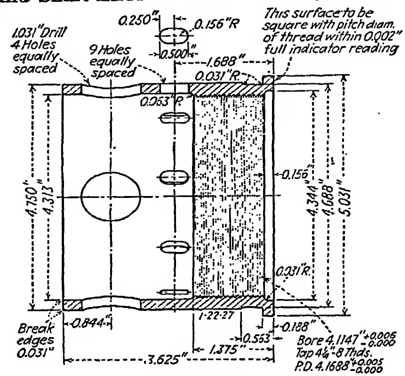
checked to an approved gage by a minute bluing prior to cutting or slitting the cone.

On rear cone No. 50A the small and large outside diameters (4.093 ±0.002 in. and $4\frac{13}{16}$ in., respectively) are to the points of intersection of the cone faces with the taper.

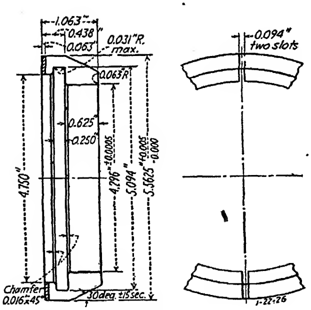
All edges are to be broken $\frac{1}{64}$ in.

PROPELLERS

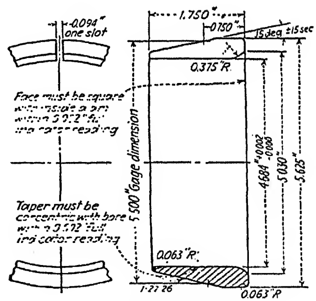
Hubs and Shaft Ends Aircraft—No. 60, Involute Spline



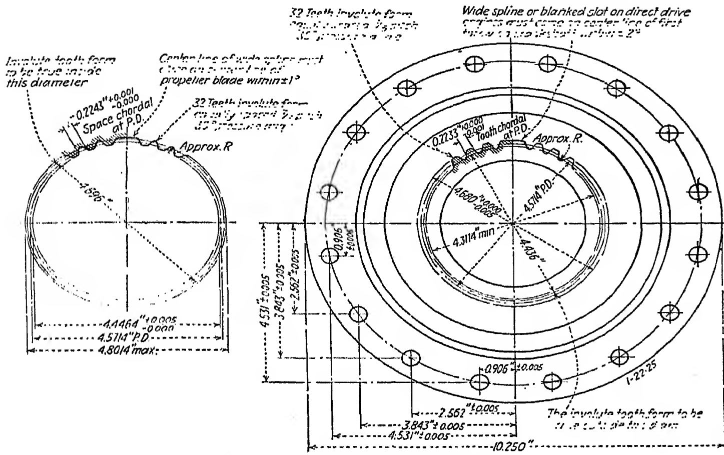
Retaining nut.



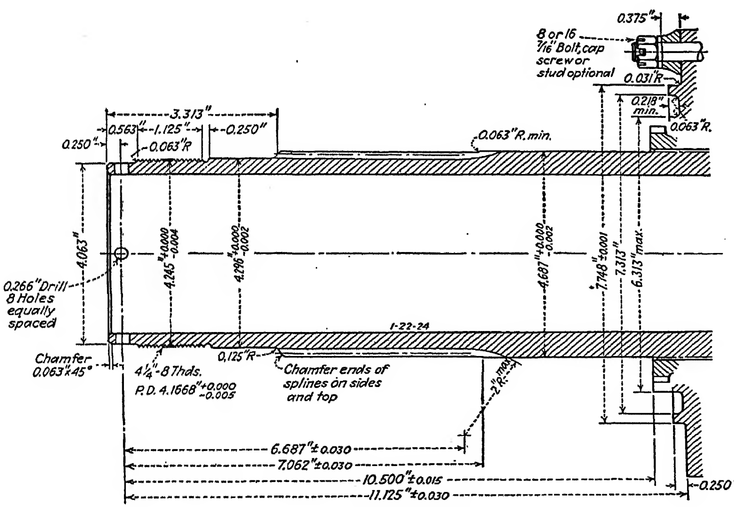
Hub front cone.



Hub rear cone.



Involute spline in hub and on shaft.



Involute spline shaft end.

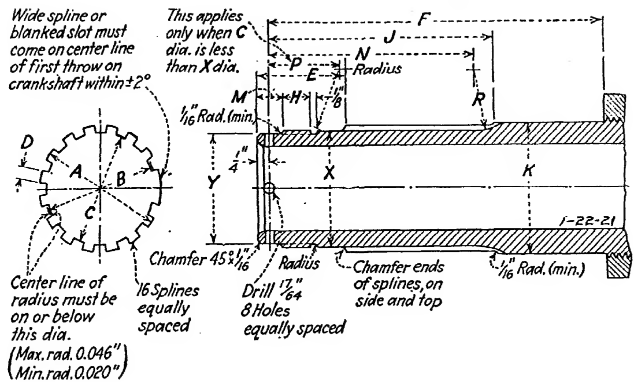


Fig. 5.—Shaft end.

Table 6.—Propeller Shaft Ends
(See Fig. 5)

S.A.E. shaft no.	A +0.000 −0.002	B max.	C min.	D ±0.0008	E	F ±0.015	H	Thread: Size and threads	Thread: Pitch diam. +0.000 −0.003	J ±0.015	K* +0.000 −0.002	M	N ±0.030	R	X* +0.000 −0.002	Y	P
10	1.992	1.781	1.689	0.1940	2 5/16	.....	1 3/16	1 11/16-12	1.631	.....	2.000	...	...	...	1.687	1 9/16	
20	2.367	2.156	2.064	0.2310	2 5/16	7.875	1 3/16	2 1/16-12	2.006	5.781	2.375	9/16	5 1/4	1 1/2	2.062	1 15/16	
30	2.617	2.406	2.314	0.2570	2 5/16	8.243	1 3/16	2 5/16-12	2.256	6.156	2.625	9/16	5 5/8	1 1/2	2.312	2 3/16	
40	3.117	2.875	2.783	0.3040	2 11/16	7.906	1 3/16	2 13/16-12	2.756	5.781	3.125	9/16	5 1/4	1 1/2	2.812	2 11/16	2 1/8
50	3.804	3.554	3.462	0.3750	2 15/16	8.562	1 1/16	3 7/16-12	3.381	6.500	3.812	1/2	6	1 1/2	3.500	3 5/16	2 3/8

* Diameters *A*, *K*, and *X* shall be concentric with each other within 0.0003 in. total indicator reading before splining operation.
American Standard 12 pitch threads.

Aircraft—Taper Type

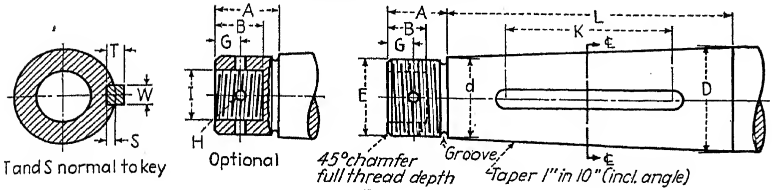


FIG. 6.

Table 7.—Taper Shaft End
(See Fig. 6)

S.A.E. shaft no.	Taper*			Key				Locking holes		
	L	*D*	*d*	*K*	*W* +0.0000 −0.0005	*T* +0.000 −0.007	*S* +0.010 −0.000	*G*	*H*	No.
00	3	1.250	0.950	1⅝	0.2495	0.250	0.154	3/16	5/32	1
0	3⅝	1.875	1.512	2¼	0.3750	0.278	0.154	¼	7/32	4
1	5 5/32	2.050	1.535	3	0.3750	0.278	0.154	15/32	13/64	5
2	7	2.362	1.662	5 7/16	0.4730	0.237	0.143			

* The taper (included angle) should vary from absolute uniformity by being from 0.000 to 0.001 in. larger at large end.

Table 8.—Taper Shaft-end Threads
(See Fig. 6)

S.A.E. shaft no.	Internal thread (optional)			External thread		
	B	*I*	Pitch diam., min.	*A**	*E*	Pitch diam. max.
00		None		1	¾ in.-16	0.7094
0	⅝	⅞ in.-18	0.8390	1 3/16	1⅜ in.-18	1.3390
1	⅞	15/16 in.-24	0.9104	1 1/16	1½ in.-18	1.4640
2	1 1/16	1 in.-14	0.9536	1¼	1 9/16 in.-12	1.5084

Thread form, American (National) Standard.
* No. 00 shaft end is designed for use of standard S.A.E. ¾-in. castle nut. All other sizes require special nuts.

Blade Ends

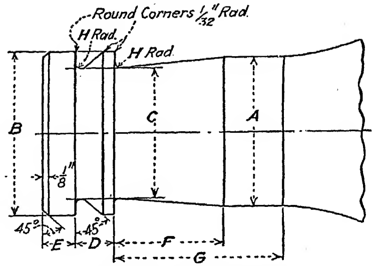
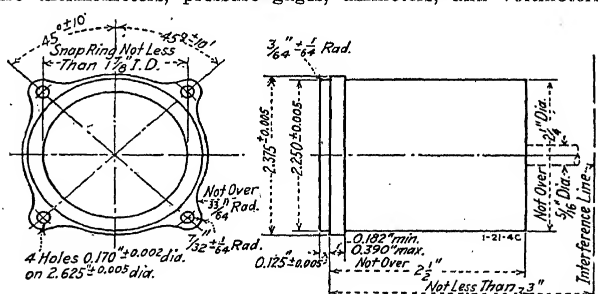


Table 9.—Blade Ends

Blade end no.	*A* +0.000 −0.003	*B* +0.000 −0.003	*C* ±0.010	*D* +0.002 −0.000	*E* ±0.010	*F* ±0.050	*G* +0.060 −0.000	*H*
00	2.250	2.495	2.000	0.500	0.4375	1.312	2.187	3/32
0	3.000	3.245	2.625	0.6875	0.562	1.687	2.937	1/8
1	3.875	4.245	3.375	0.875	0.750	2.375	3.750	5/32
1½	4.1875	4.620	3.6875	1.0625	0.875	2.6875	4.187	5/32
2	4.500	4.995	3.875	1.250	1.000	3.125	4.625	5/32
3	5.000	5.620	4.312	1.375	1.125	3.438	5.125	3/16

INSTRUMENT CASES AND MOUNTINGS

These specifications give the basic mounting and case dimensions for aircraft instruments in two sizes. Instruments having 1⅞-in. (nominal) dial size are thermometers, pressure gages, ammeters, and voltmeters. All

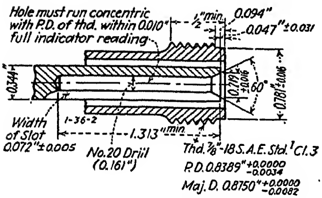


Dimensions for 1⅞-in. dial instruments.

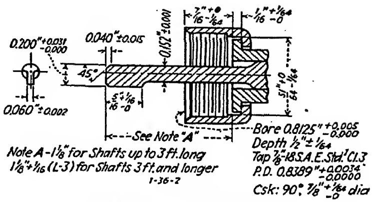
other instruments use the 2¾-in. (nominal) dial size. On the drawing of the 1⅞-in. instrument, an interference line has been indicated to provide sufficient clearance for connection tubing on thermometers and pressure gages.

TACHOMETER DRIVE

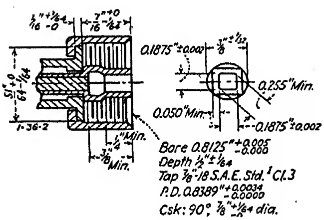
Drive for Mechanical Types



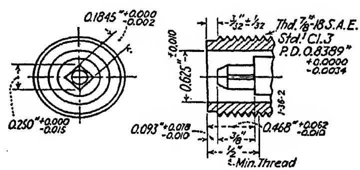
Engine connection.



Engine end of drive shaft.

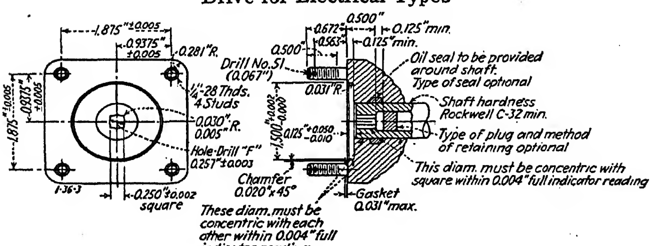


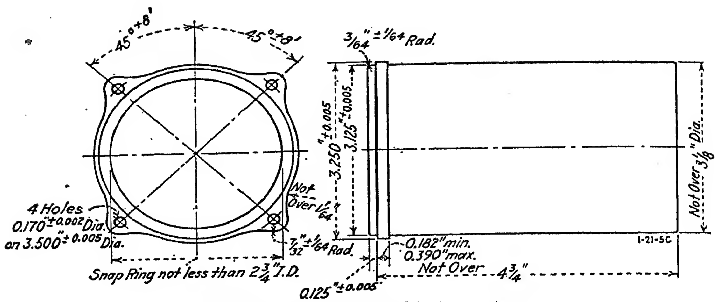
Tachometer end of drive shaft.



Tachometer connection.

Drive for Electrical Types





Dimensions for 2¾-in. dial instruments.

SPARK PLUGS

The original standard for the ⅞ in.-18 spark plug which had a ⅞ in. hexagon was adopted by the Mechanical Branch of the Association of Licensed Automobile Manufacturers in October, 1908. This standard was taken over by the S.A.E. in 1910 and in January, 1915, extended to include definite thread limits and the addition of the 1⅛ in. hexagon. In March, 1923, three terminals, the post, ball, and slip types were recommended by the Electrical Equipment Division and adopted as S.A.E. recommended

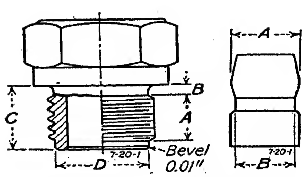


FIG. 7.—Motor-vehicle plugs and terminal.

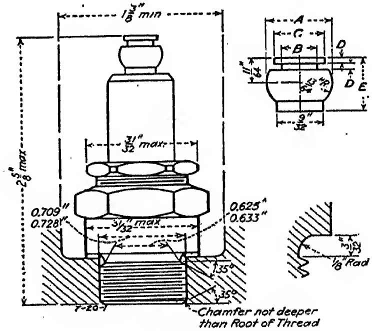


FIG. 8.—Aircraft plug and terminal.

practice. At that time these terminals were commonly made to two thread sizes, No. 8-32 and 0.183-32, both of which were so generally used that this dual standard was retained until the terminal specification was revised in January, 1935, to include only the permanent, fixed post type that was coming into common use.

The motorcycle plug threads were slightly larger than, and the tapped holes slightly smaller than, for the aircraft plugs, but in May, 1930, all 18 mm. plug threads were made the same as for the aircraft plugs.

Table 10.—Spark-plug Dimensions
(See Figs. 7 and 8)

Spark plug	Hexgon size, in. ± 0.005	Thread length, A ± 1/64	Neck length, B	Skirt length, C	Pilot diam., D, max.
7/8 in.-18	15/16 or 1 1/8	3/8	1/8	5/8 or 15/16	25/32
18-1.5 mm.* (motor vehicle)	1	13/32	3/32	1/2	5/8
18-1.5 mm.* (aircraft)†	1 or 1 1/16‡	13/32	3/32	1/2	5/8

Terminals

Terminals for	A +0.000 −0.003	B +0.000 −0.008	A +0.005 −0.000	B +0.005 −0.000	C +0.005 −0.000	D +0.005 −0.000	E +0.005 −0.000
Motor vehicle §	0.250	0.220					
Aircraft ‖	.....	.....	0.406	0.218	0.312	0.045	0.386

Threads

Spark plug	Major diam.		Pitch diam.		Minor diam., max.
	Max.	Min.	Max.	Min.	
7/8 in.-18	0.8750	0.8688	0.8384	0.8343	0.8068
18-1.5 mm.	0.7077 in. 17.975 mm.	0.7028 in. 17.850 mm.	0.6693 in. 17.001 mm.	0.6644 in. 16.876 mm.	0.6246 in. 15.864 mm.

* Form of thread is International Standard, which is the same as the American Standard (B1.1-1935), except that the truncation at the root of the thread is half as much as in the American Standard thread.
† The thread and body dimensions, except the depth of chamfer at the skirt, are substantially the same as those recommended by the International Aircraft Standards Conference at London in April, 1918. The spark-plug terminal shall be at least 3/4 in. from the nearest metal object.
‡ Optional small-size hexagon.
§ The post type terminal is for use on the 7/8 in.-18 and the 18-1.5 mm. spark plug for motor vehicles, marine and industrial engines, and motorcycles.
‖ The ball type terminal is for use on the 18-1.5 mm. spark plug for aircraft.

Table 11.—Tapped Hole Threads

Spark plug	Major diam., min.	Pitch diam.		Minor diam.	
		Max.	Min.	Max.	Min.
7/8 in.-18	0.8750	0.8430	0.8389	0.8209	0.8149
18-1.5 mm.	0.7160 in. 18.187 mm.	0.6762 in. 17.176 mm.	0.6713 in. 17.051 mm.	0.6378 in. 16.201 mm.	0.6329 in. 16.076 mm.

Tapped Hole Countersink.—The diameter of the countersink or counterbore of the tapped hole in the cylinder head shall not exceed the minimum major thread diameter by more than 0.005 in.

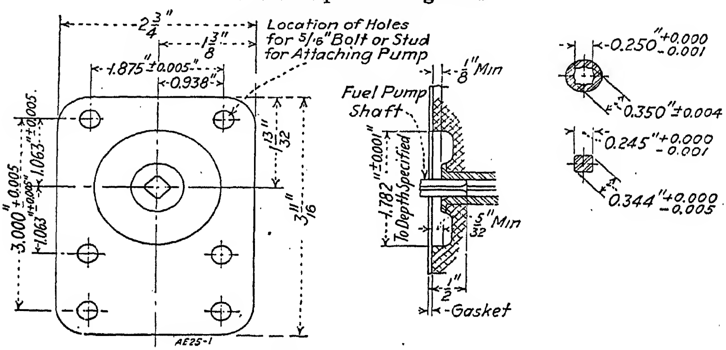
Thread Gages.—In order to keep the wear on threading tools within the permissible limits, the threads in the spark-plug "Go" (ring) gage shall be truncated to the maximum minor diameter of the spark plug, and in the

tapped hole "Go" (plug) gage, to the minimum major diameter of the tapped hole.

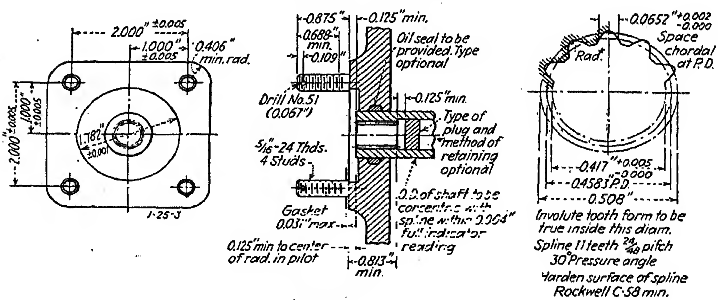
Metric Conversions.—The factor 1 mm. = 0.03937 in. (1 in. = 25.4 mm.) was used for the conversion of metric values to inch equivalents in the accompanying tables, the equivalents being figured to six decimals.

ACCESSORIES MOUNTINGS

Fuel Pump Mounting Pads

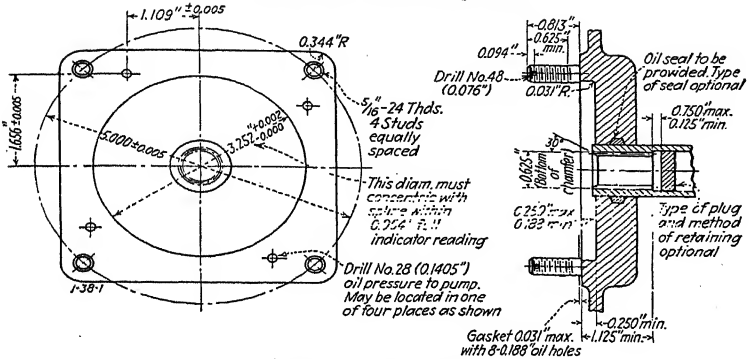


Old-type pad (Aug. 1928).

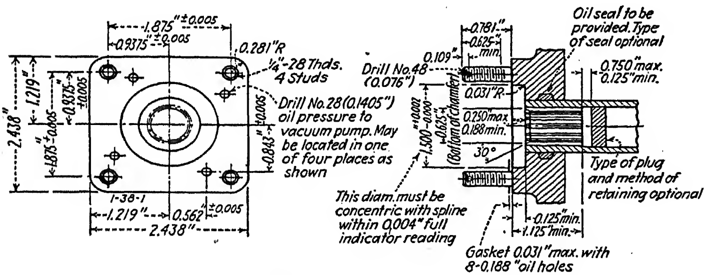


Square-type pad.

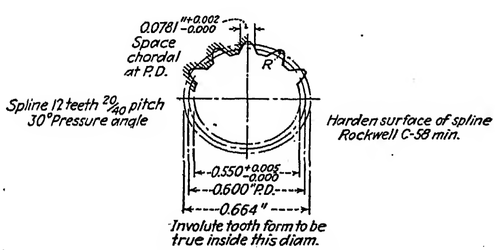
Vacuum Pump Mounting Pads



Medium pump mounting.



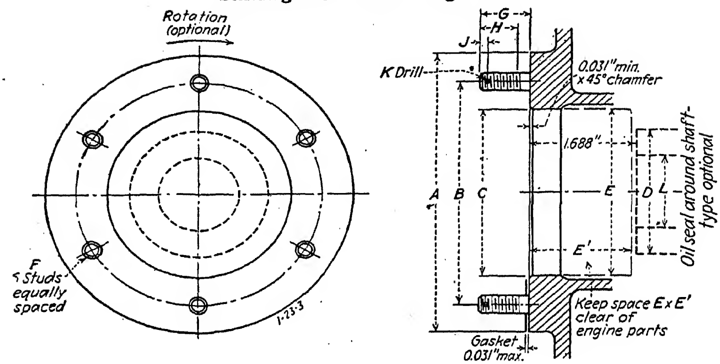
Small pump mounting.

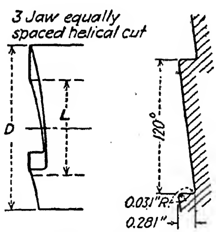


Spline for both mountings.

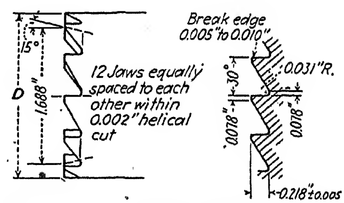
S.A.E. Standard

Starting Motor Mounting Pads





Three-jaw clutch development.

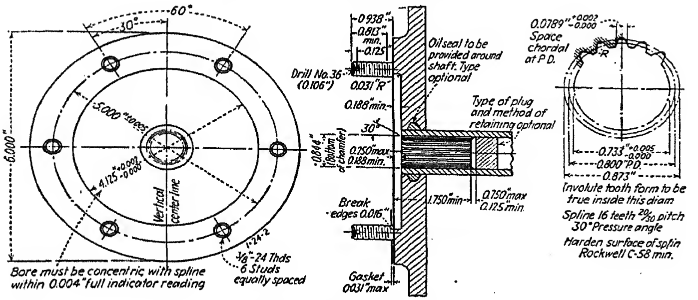


Twelve-jaw clutch development at 2.375 in. diameter.

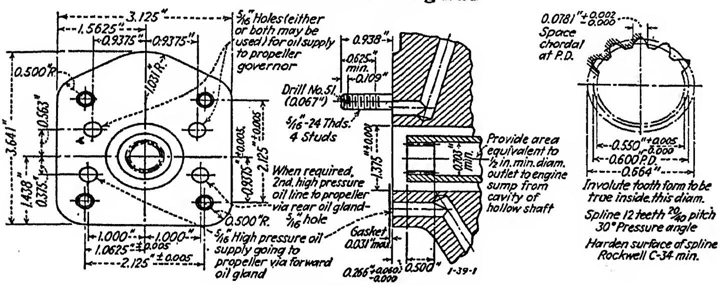
Table 12.—Starter Mounting and Clutch Dimensions

Starter size	Clutch jaws	A	B ± 0.005	C $+0.003$ -0.000	D	Clearance E	Clearance E'	F studs	G	H	J	K drill	L
Small........	3	5.000	4.000	3.000	2.250	3.000	1.625	5/16-24	0.813	0.625	.....	......	1.000
Medium.....	3 or 12	6.000	5.000	4.125	2.250	4.125	1.500	3/8-24	0.938	0.813	0.125	No 36. (0.106)	1.688 max.
Large........	3 or 12	7.000	5.750	4.625	3.250	4.625	1.500	7/16-20	1.063	0.813	0.125	No. 36 (0.106)	1.688 max.

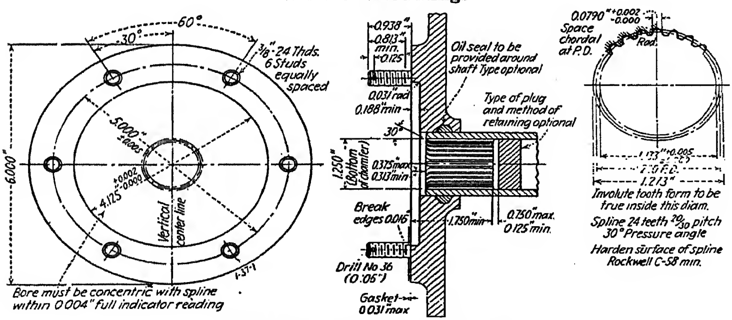
AIRCRAFT ENGINE PAD



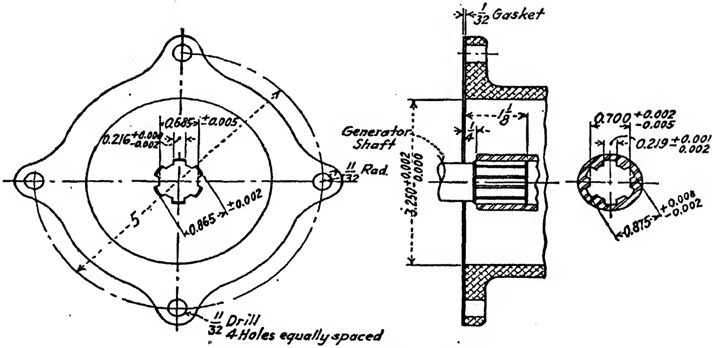
Governor Mounting Pad



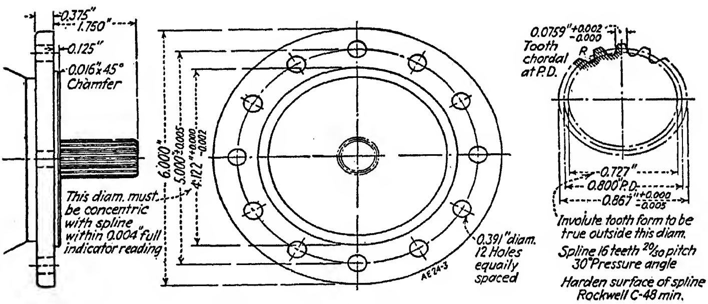
Generator Mountings



Generator mounting pad, 6-bolt type.

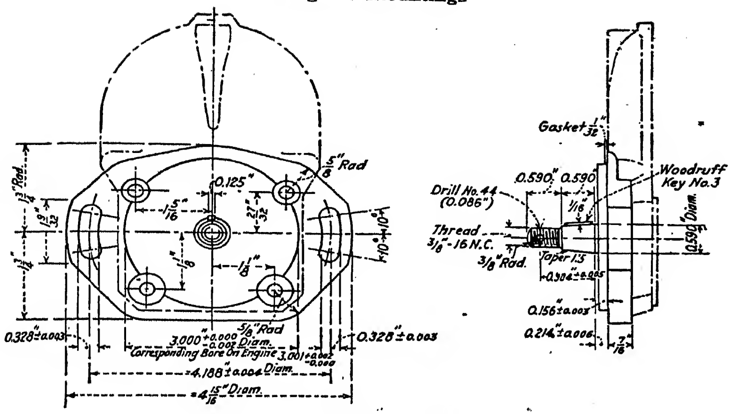


Generator mounting pad, 4-bolt type.

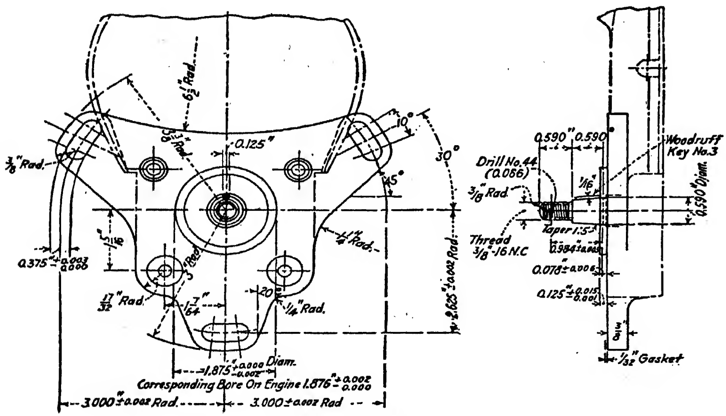


Generator mounting pad, 12-bolt type.

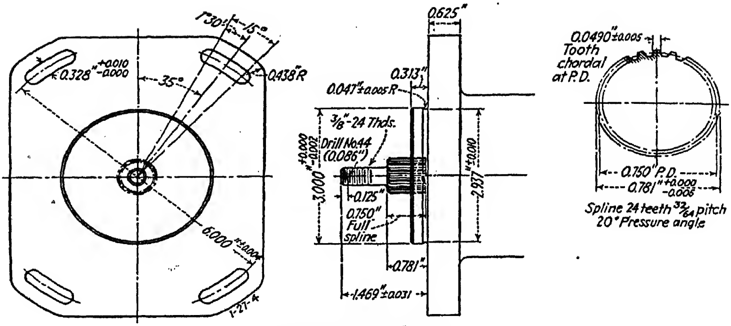
Magneto Mountings



Two-bolt flanged type.

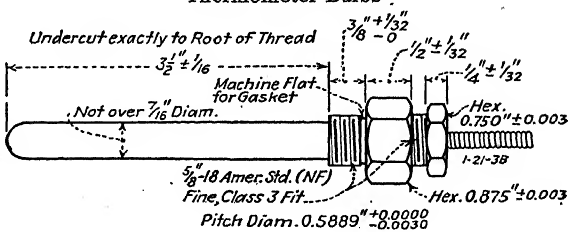


Three-bolt flanged type.

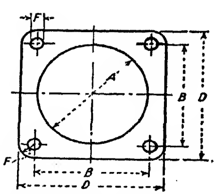


Four-bolt flanged type.

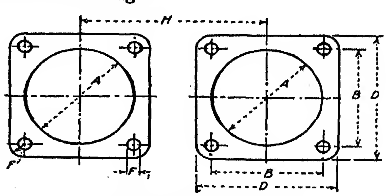
Thermometer Bulbs



Carburetor Flanges

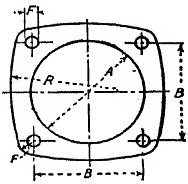


Single barrel (Table 15).

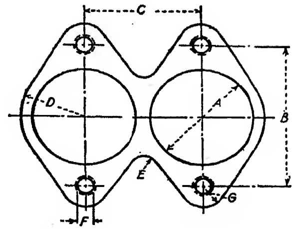


Double barrel (Table 16).

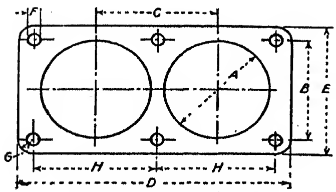
Fig. 9.



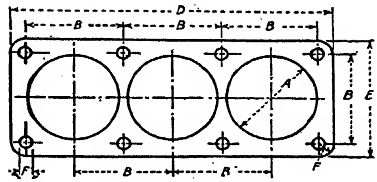
Single barrel (Table 15).



Double barrel (Table 16).



Double barrel (Table 14).



Triple barrel (Table 14).

Fig. 10.

All types of flange shall be of the following thickness.

Table 13.—Flange Thickness

Stud Size	Flange Thickness, In.
1/4	5/16
5/16	3/8
3/8	13/32

Table 14.—Four- and Eight-bolt Flanges
(See Fig. 9)

Nominal size		A	B	D	F	H*
No.	Diam.					
2	1 1/4	1 7/16	1 3/4	2 5/16	9/32	....
3	1 1/2	1 11/16	1 15/16	2 1/2	9/32	....
4	1 3/4	1 15/16	2 3/16	2 3/4	9/32	4 3/8
5	2	2 3/16	2 11/32	3 1/32	11/32	4 7/8
6	2 1/4	2 7/16	2 1/2	3 3/16	11/32	5 1/8
7	2 1/2	2 11/16	2 3/4	3 7/16	11/32	5 1/2
8	2 3/4	2 15/16	3	3 11/16	11/32	5 5/8
9	3	3 3/16	3 3/16	4	13/32	....
10*	3 1/4	3 7/16	3 7/16	4 1/4	13/32	6 5/16

* For double-barrel eight-bolt flange type only.

Table 15.—Single-barrel Four-bolt Flange
(See Fig. 9)

Nominal size		*A*	*B*	*F*	*R*
No.	Diam.				
10	3 1/4	3 7/16	3 3/8	1 3/32	2 1/8
11	3 1/2	3 11/16	3 1/2	1 3/32	2 1/4
12	3 3/4	3 15/16	3 3/4	1 3/32	2 3/8
13	4	4 3/16	4	1 3/32	2 1/2

Table 16.—Double-barrel, Four-bolt Flange
(See Fig. 9)

Nominal size		*A*	*B*	*C*	*D*	*E*	Tap *F*	*G*
No.	Diam.							
4	1 3/4	1 15/16	3 1/8	2 3/16	1 1/4	9/32	7/16-14	1 3/32
5	2	2 3/16	3 3/8	2 7/16	1 3/8	9/32	7/16-14	1 3/32
6	2 1/4	2 7/16	3 5/8	2 11/16	1 1/2	9/32	7/16-14	1 5/32
7	2 1/2	2 11/16	4	2 15/16	1 21/32	9/32	7/16-14	1 5/32
8	2 3/4	2 15/16	4 1/4	3 3/16	1 25/32	9/32	7/16-14	1 7/32

Six-bolt Flange
(See Fig. 10)

Nominal size		*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
No.	Diam.								
7	2 1/2	2 11/16	2 13/16	2 15/16	6 5/8	3 11/16	1 1/32	7/16	2 7/8
8	2 3/4	2 15/16	3	3 3/16	7 1/16	3 7/8	1 1/32	7/16	3 3/32
9	3	3 3/16	3 3/16	3 7/16	7 9/16	4 1/8	1 3/32	1 5/32	3 5/16
10	3 1/4	3 7/16	3 7/16	3 11/16	8 1/16	4 3/8	1 3/32	1 5/32	3 9/16
11	3 1/2	3 11/16	3 11/16	3 15/16	8 9/16	4 5/8	1 3/32	1 5/32	3 13/16
12	3 3/4	3 15/16	3 15/16	4 3/16	9 1/16	4 7/8	1 3/32	1 5/32	4 1/16

Table 17.—Triple-barrel Eight-bolt Flange
(See Fig. 10)

Nominal size		*A*	*B*	*D*	*E*	*F*
No.	Diam.					
3	1 1/2	1 11/16	1 15/16	6 3/8	2 1/2	9/32
4	1 3/4	1 15/16	2 3/16	7 1/8	2 3/4	9/32
5	2	2 3/16	2 7/16	8	3 1/8	1 1/32

LANDING GEARS

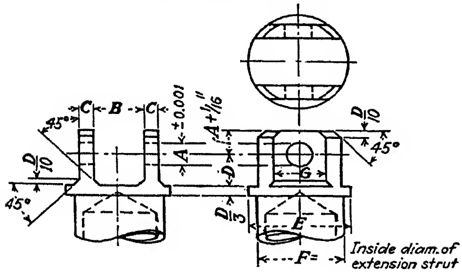


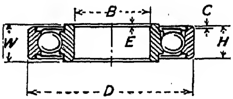
Table 18.—Shock-absorber Strut Ends

Static load per strut		Ream A	B	C	D	E min.
0	500	0.3125	0.630 0.625	0.260 0.250	9/16	1.25
500	1,000	0.3750	0.755 0.750	0.300 0.290	5/8	1.50
1,000	1,500	0.3750	0.755 0.750	0.300 0.290	5/8	1.50
1,500	2,000	0.4375	0.880 0.875	0.330 0.320	11/16	1.75
2,000	2,500	0.5000	1.010 1.000	0.370 0.360	3/4	1.93
2,500	3,000	0.5625	1.135 1.125	0.410 0.400	13/16	2.12
3,000	4,000	0.5625	1.135 1.125	0.410 0.400	13/16	2.12
4,000	5,000	0.6250	1.260 1.250	0.440 0.430	7/8	2.43
5,000	6,000	0.7500	1.510 1.500	0.500 0.490	1	2.93
6,000	8,000	0.7500	1.510 1.500	0.500 0.490	1	2.93
8,000	10,000	0.8750	1.760 1.750	0.550 0.540	1 1/8	3.25
10,000	12,000	0.8750	1.760 1.750	0.550 0.540	1 1/8	3.25

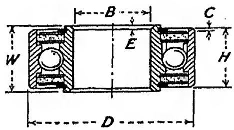
A = required diameter for bending and double shear on A.N. standard bolt.
B = $2A$ to allow for unilink of universal joint.
C = 1.5 × tie-rod-fork thickness.
$2C + B$ = grip of A.N. standard bolt.
$D = A + 1/4$ in. for clearance, as radius of lug = A.
E = minimum diameter of flange when flat $G = 1.75 \times A$.
Note: This design is based upon the use of steel of minimum tensile strength of 125,000 lb. per sq. in.

Ball Bearings

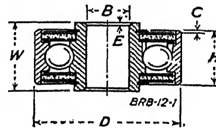
These bearings constitute series developed especially for uses in aircraft for which the regular types are not so well suited. They are dimensioned



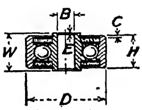
Type K-A.



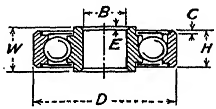
Type KF-A.



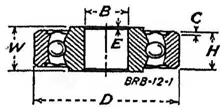
Type KF.



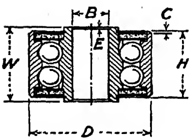
Type KF-H.



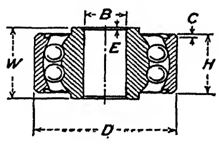
Type K.



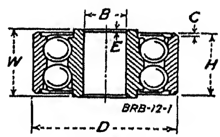
Type KS.



Type DF.



Type DS.



Type D.

entirely in decimal inches, the bores being in even increments of $\frac{1}{16}$ in. as indicated by the numbers in the bearing designations. The several types are illustrated in the accompanying illustrations.

Table 19.—Aircraft Ball Bearings

No.	Bore B, tolerance, +0.0000 −0.0005	Outside diam. D, tolerance, +0.0000 −0.0005	Individual ring width, tolerance, +0.000 −0.005		Outer ring 45 deg. Chamfer C, tolerance, +0.015 −0.000	Inner ring 45 deg. Chamfer E, tolerance, +0.015 −0.000	Illustrations
			Inner ring W	Outer ring H			
K 3-A	0.1900	0.6250	0.297	0.234	0.016	0.005	Series K-A
K 4-A	0.2500	0.7500	0.281	0.219	0.016	0.016	
K 5-A	0.3125	0.8125	0.297	0.234	0.016	0.016	
K 6-A	0.3750	0.8750	0.313	0.250	0.016	0.016	
K 8-A	0.5000	1.1250	0.375	0.313	0.016	0.016	
K 10-A	0.6250	1.3750	0.406	0.344	0.032	0.032	
K 12-A	0.7500	1.6250	0.437	0.375	0.032	0.032	
K 16-A	1.0000	2.0000	0.500	0.4375	0.032	0.032	
K 20-A	1.2500	2.2500	0.500	0.4375	0.032	0.032	
KF 3-A	0.1900	0.6250	0.500	0.406	0.016	0.005	Series KF-A
KF 4-A	0.2500	0.7500	0.500	0.437	0.016	0.016	
KF 5-A	0.3125	0.8125	0.562	0.500	0.016	0.016	
KF 6-A	0.3750	0.8750	0.562	0.500	0.016	0.016	
KF 8-A	0.5000	1.1250	0.625	0.562	0.016	0.016	
KF 10-A	0.6250	1.3750	0.687	0.625	0.032	0.032	
KF 12-A	0.7500	1.6250	0.750	0.687	0.032	0.032	
KF 16-A	1.0000	2.0000	0.812	0.750	0.032	0.032	
KF 20-A	1.2500	2.2500	0.812	0.750	0.032	0.032	
KF 3	0.1900	0.7774	0.495	0.406	0.016	0.010	Series KF
KF 4	0.2500	0.9014	0.620	0.422	0.016	0.016	
KF 5	0.3125	1.2500	0.745	0.625	0.016	0.016	
KF 6	0.3750	1.4375	0.870	0.687	0.016	0.016	
KF 8	0.5000	1.6875	0.932	0.750	0.032	0.032	
KF 10	0.6250	1.9375	0.932	0.781	0.044	0.044	
KF 3-H	0.1900	1.0000	0.561	0.500	0.022	0.010	Series KF-H
KF 4-H	0.2500	1.0625	0.625	0.531	0.032	0.022	
K 3-L	0.1900	0.625	0.245	0.203	0.016	0.005	Series K
K 3	0.1900	0.7774	0.297	0.270	0.022	0.010	
K 4	0.2500	0.9014	0.484	0.335	0.032	0.022	
K 5	0.3125	1.2500	0.5575	0.375	0.032	0.022	
K 6	0.3750	1.4375	0.620	0.469	0.032	0.022	
K 8	0.5000	1.6875	0.620	0.500	0.044	0.032	
K 10	0.6250	1.9375	0.620	0.500	0.044	0.044	
KS 3	0.1900	0.7774	0.297	0.270	0.022	0.010	Series KS*
KS 4	0.2500	0.9014	0.484	0.335	0.032	0.022	
KS 5	0.3125	1.2500	0.5575	0.375	0.032	0.022	
KS 6	0.3750	1.4375	0.620	0.469	0.032	0.022	
KS 8	0.5000	1.6875	0.620	0.500	0.044	0.032	
KS 10	0.6250	1.9375	0.8125	0.625	0.044	0.044	
DF 5	0.3125	1.2500	1.0000	0.8750	0.032	0.022	Series DF
DF 6	0.3750	1.4375	1.1250	1.0000	0.032	0.022	
DF 8	0.5000	1.6875	1.1875	1.0625	0.044	0.032	
DS 3	0.1900	0.7774	0.500	0.392	0.022	0.010	Series DS
DS 4	0.2500	0.9014	0.687	0.464	0.032	0.022	
DS 5	0.3125	1.2500	0.812	0.656	0.032	0.022	
DS 6	0.3750	1.4375	0.937	0.750	0.032	0.022	
DS 8	0.5000	1.6875	1.000	0.812	0.044	0.032	
DS 10	0.6250	1.9375	1.125	0.937	0.044	0.044	
D 3	0.1900	0.7774	0.495	0.473	0.022	0.010	Series D
D 4	0.2500	0.9014	0.620	0.491	0.032	0.022	
D 5	0.3125	1.2500	0.745	0.687	0.032	0.022	
D 6	0.3750	1.4375	0.870	0.794	0.032	0.022	
D 8	0.5000	1.6875	0.932	0.856	0.044	0.032	
D 10	0.6250	1.9375	0.995	0.920	0.044	0.044	

* Permissible misalignment in either direction is 10 deg. with the exception of KS 5, where it is 9 deg.

Wheel Hubs

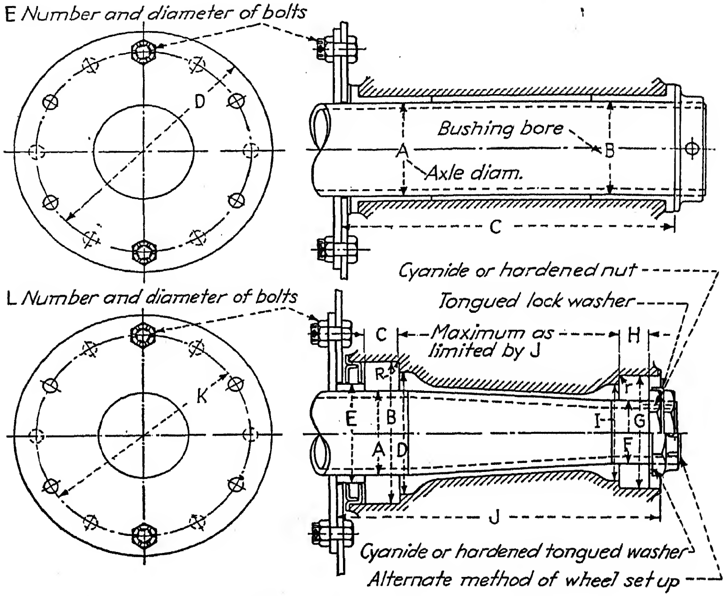


Table 20.—Plain Bearing Wheel-hub and Axle Dimensions

Wheel size	Nominal axle-tube diam., in.	*A*, finished-axle diam., in., tolerance, +0.001 −0.001	*B*, bushing-bore diam., in., tolerance, +0.001 −0.001	*C*, Hub length, in.	*D*, Bolt circle diam., in.	*E*, bolts No.	*E*, bolts Diam.
10 × 3	¾	0.750	0.753	4			
14 × 3	¾	0.750	0.753	4			
18 × 3	1¼	1.250	1.254	5	4	6	¼
24 × 4	1½	1.500	1.504	6 or 5	4	6	¼
28 × 4	1¾	1.719	1.723	6	4	6	¼
30 × 5	2¼	2.188	2.193	7¼	4¾	6	⅜
32 × 6	2¼	2.188	2.193	7¼	4¾	6	⅜
36 × 8	2¾	2.688	2.693	8½	5¾	12	⅜
44 × 10	3¼	3.188	3.194	10	8	12	9/16
54 × 12	4	3.937	3.944	12	8	12	9/16

Table 21.—Antifriction Bearing Wheel-hub and Axle Dimensions

	A	B	C	R	D	E	F*	G*	H*	r*	I*	J	K	L	
Wheel size	Inner axle diam., in., tolerance, +0.000 −0.001	Wheel bore diam., in., tolerance, +0.000 −0.001	Inner bearing width, in.	Radius of hub bore inner position, in. tolerance, +0.000 − 1/64	Inner bearing shoulder diam., in., max.	Spacer outside diam., in.	Outer axle, diam., in., tolerance, +0.000 −0.001	Wheel bore, diam., in., tolerance, +0.000 −0.001	Outer bearing, width, in.	Radius of hub bore, outer position, in., tolerance, +0.000 − 1/64	Outer bearing shoulder diam., in., max.	Wheel hub, length, in.	Bolt circle, diam., in.	Bolts No.	Bolts Diam.
Tail wheels:															
10 × 3	0.750	1.624	15/32	1/32	1 3/8	1	0.750	1.624	15/32	1/32	1 3/8	4†			
14 × 3	0.750	1.624	15/32	1/32	1 3/8	1	0.750	1.624	15/32	1/32	1 3/8	4			
18 × 3	1.250	2.312	37/64	1/32	2	1 5/8	1.000	1.968	17/32	1/32	1 3/4	5	4	6	1/4
Landing wheels:															
24 × 4	1.500	2.687	5/8	3/64	2 3/8	1 7/8	1.000	1.968	17/32	1/32	1 3/4	6 or 5	4	6	1/4
28 × 4	1.500	2.687	5/8	3/64	2 3/8	1 7/8	1.000	1.968	17/32	1/32	1 3/4	6	4	6	1/4
30 × 5	2.000	3.374	3/4	3/64	3	2 1/2	1.500	2.687	5/8	3/64	2 3/8	7 1/4	4 3/4	6	3/8
32 × 6	2.000	3.374	3/4	3/64	3	2 1/2	1.500	2.687	5/8	3/64	2 3/8	7 1/4	4 3/4	6	3/8
36 × 8	2.500	4.124	27/32	1/16	3 3/4	3	2.000	3.374	3/4	3/64	3	8 1/2	5 3/4	12	3/8
44 × 10	3.000	4.781	31/32	1/16	4 1/4	3 9/16	2.500	4.124	27/32	1/16	3 3/4	10	8	12	9/16
54 × 12	3.750	5.843	1 1/8	3/32	5 1/4	4 3/8	3.000	4.781	31/32	1/16	4 1/4	12	8	12	9/16

* Use of a tapered axle necessitating smaller outside bearing is optional. Straight axles should use the same outer bearing as inner bearing, as listed.
† Measurement *J* for tail wheels is taken from inside fork faces.

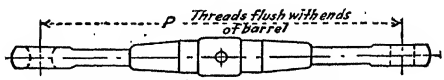
RIGGING CONNECTIONS

Turnbuckles

Turnbuckle parts shall be subjected to a tensile test after plating and shall withstand the test load specified.

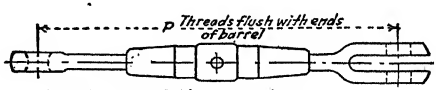
The parts shall be machined preferably from heat-treated, cold-drawn, or cold-rolled bars. If forks are not made from heat-treated, cold-drawn, or cold-rolled bars, they shall be heat-treated after machining to give the physical properties specified.

Turnbuckle parts meeting the tensile test without breaking shall be held in a square-nose vise and bent through an angle of 90 deg. without failing or cracking.



Assembly No.1 Cable-Eye and Pin-Eye

Assembly No.2 Cable-Eye and Cable-Eye



Assembly No.3 Cable-Eye and Fork

Note: P = 4½ in., assembled length—short type.
P = 8 in., assembled length—long type.

Table 22.—Turnbuckle Weights—General Information

Short type		Long type	
Strength, lb.	Approximate weight, lb.	Strength, lb.	Approximate weight, lb.
800	0.030	1,600	0.094
1,600	0.065	2,100	0.116
2,100	0.084	3,200	0.172
3,200	0.112	4,600	0.250
4,600	0.165	6,100	0.368
		8,000	0.420
		12,500	0.630
		17,500	0.935

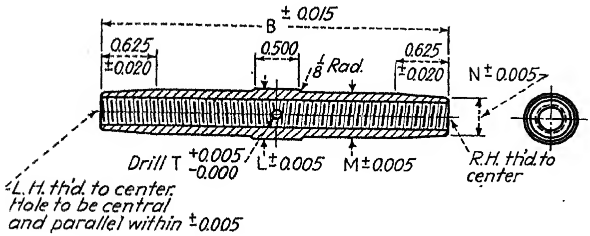


Table 23.—Barrel

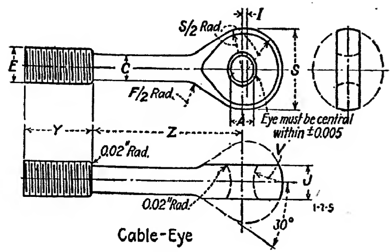
Strength, lb.	Thread*	L	M	N	B	T
			Short			
800	6-40	0.250	0.219	0.188	2.25	0.125
1,600	10-32	0.375	0.281	0.250	2.25	0.125
2,100	12-28	0.375	0.328	0.281	2.25	0.125
3,200	¼-28	0.438	0.391	0.328	2.25	0.125
4,600	5⁄16-24	0.500	0.438	0.406	2.25	0.125
			Long			
1,600	10-32	0.375	0.281	0.250	4.00	0.125
2,100	12-28	0.375	0.328	0.281	4.00	0.125
3,200	¼-28	0.438	0.391	0.328	4.00	0.125
4,600	5⁄16-24	0.500	0.438	0.406	4.00	0.125
6,100 8,000	⅜-24	0.625	0.594	0.469	4.00	0.125
12,500	7⁄16-20	0.750	0.688	0.563	4.25	0.188
17,500	½-20	0.875	0.813	0.625	4.25	1.88

* Threads are American Standard (N.F.), with Class 3 tolerances. N.F. indicates National fine pitch. Tolerances are ±0.010 except where otherwise indicated.

Barrels shall be made of rolled brass to provide the following physical properties:

Physical Properties

Tensile strength (min.), lb. per sq. in.	67,000
Yield point (min.), lb. per sq. in.	45,000
Elongation (min.) in 2 in., per cent	22
Reduction of area (min.), per cent	45



Cable-Eye

Table 24.—Cable-eye Dimensions

Hand	Strength, lb.	Thread*	E	A +0.010 −0.000	C +0.006 −0.000	F/2	I +0.010 −0.000	J	S	V	Y ±0.047	Z +0.031 −0.015
						Long						
Left / Right	1,600	10-32	0.190 +0.0000 −0.0054	0.219	0.133	0.156	0.031	0.188	0.500	0.172	0.500	2.000
Left / Right	2,100	12-28	0.216 +0.0000 −0.0062	0.219	0.155	0.156	0.031	0.188	0.500	0.172	0.563	2.000
Left / Right	3,200	¼-28	0.250 +0.0000 −0.0062	0.281	0.189	0.219	0.047	0.219	0.625	0.203	0.625	2.000
Left / Right	4,600	5/16-24	0.3125 +0.0000 −0.0066	0.313	0.243	0.250	0.047	0.281	0.688	0.250	0.750	2.000
Left / Right	6,100	⅜-24	0.375 +0.0000 −0.0066	0.344	0.256	0.281	0.063	0.281	0.750	0.313	0.875	2.000
Left / Right	8,000	⅜-24	0.375 +0.0000 −0.0066	0.375	0.306	0.281	0.063	0.328	0.875	0.375	0.875	2.000

Table 24.—Cable-eye Dimensions (*Continued*)

Hand	Strength, lb.	Thread*	E	A +0.010 −0.000	C +0.006 −0.000	$F/2$	I +0.010 −0.000	J	S	V	Y ±0.047	Z +0.031 −0.015
						Long						
Left / Right	12,500	$\frac{7}{16}$-20	0.4375 +0.0000 −0.0072	0.469	0.362	0.359	0.078	0.375	1.063	0.453	1.000	2.375
Left / Right	17,500	$\frac{1}{2}$-20	0.500 +0.0000 −0.0072	0.563	0.425	0.406	0.078	0.469	1.188	0.500	1.000	2.625
Left / Right	800	6-40	0.138 +0.0000 −0.0048	0.188	0.094	0.125	0.031	0.125	0.375	0.094	0.375	1.125
Left / Right	1,600	10-32	0.190 +0.0000 −0.0054	0.219	0.133	0.156	0.031	0.188	0.500	0.172	0.500	1.125
Left / Right	2,100	12-28	0.216 +0.0000 −0.0062	0.219	0.155	0.156	0.031	0.188	0.500	0.172	0.563	1.125
Left / Right	3,200	$\frac{1}{4}$-28	0.250 +0.0000 −0.0062	0.281	0.189	0.219	0.047	0.219	0.625	0.203	0.625	1.125
Left / Right	4,600	$\frac{5}{16}$-24	0.3125 +0.0000 −0.0066	0.313	0.243	0.250	0.047	0.281	0.688	0.250	0.750	1.125

* Threads are American Standard (N.F.), with Class 3 tolerances. N.F. indicates National fine pitch. Finished sizes include plating or protective coating. Tolerances are ±0.010 except where otherwise indicated.

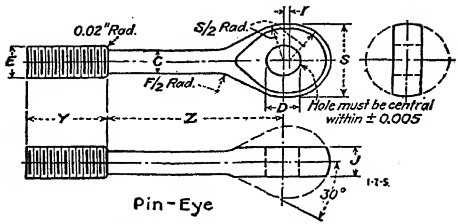
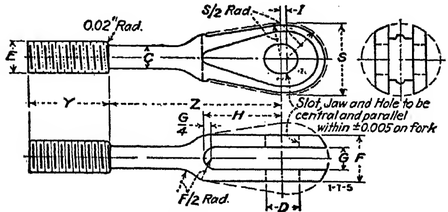


Table 25.—Pin-eye Dimensions

Strength, lb.	Thread*	E	D +0.010 −0.000	C +0.006 −0.000	F/2	I +0.010 −0.000	J	S	Y ±0.047	Z +0.031 −0.015
					Short					
800	6-40	0.1218 +0.0000 −0.0017	0.188	0.094	0.125	0.031	0.125	0.375	0.375	1.125
1,600	10-32	0.1697 +0.0000 −0.0019	0.188	0.133	0.156	0.031	0.188	0.500	0.500	1.125
2,100	12-28	0.1928 +0.0000 −0.0022	0.188	0.155	0.156	0.031	0.188	0.500	0.563	1.125
3,200	1/4-28	0.2268 +0.0000 −0.0022	0.250	0.189	0.219	0.047	0.219	0.625	0.625	1.125
4,600	5/16-24	0.2854 +0.0000 −0.0024	0.313	0.243	0.250	0.047	0.281	0.688	0.750	1.125
					Long					
1,600	10-32	0.1697 +0.0000 −0.0019	0.188	0.133	0.156	0.031	0.188	0.500	0.500	2.000
2,100	12-28	0.1928 +0.0000 −0.0022	0.188	0.155	0.156	0.031	0.188	0.500	0.563	2.000
3,200	1/4-28	0.2260 +0.0000 −0.0022	0.250	0.189	0.219	0.047	0.219	0.625	0.625	2.000
4,600	5/16-24	0.2854 +0.0000 −0.0024	0.313	0.243	0.250	0.047	0.281	0.688	0.750	2.000
6,100	3/8-24	0.3479 +0.0000 −0.0024	0.375	0.256	0.281	0.063	0.281	0.750	0.875	2.000
8,000	3/8-24	0.3479 +0.0000 −0.0024	0.375	0.306	0.281	0.063	0.328	0.875	0.875	2.000
12,500	7/16-20	0.4050 +0.0000 −0.0026	0.438	0.362	0.359	0.078	0.375	1.063	1.000	2.375
17,500	1/2-20	0.4675 +0.0000 −0.0026	0.500	0.425	0.406	0.078	0.469	1.188	1.000	2 625

* Threads are American Standard (N.F.), with Class 3 tolerances. N.F. indicates National fine pitch. Finished sizes include plating or protective coating. Tolerances are ± 0.010 except where otherwise indicated.



Fork

Table 26.—Fork Dimensions

Strength, lb.	Thread*	E	C +0.006 −0.000	D +0.010 −0.000	F +0.010 −0.005	G +0.020 −0.000	H	I +0.010 −0.000	S	Y ±0.047	Z +0.031 −0.015
					Short						
800	6-40	0.138 +0.0000 −0.0048	0.094	0.188	0.250	0.109	0.375	0.031	0.375	0.375	1.125
1,600	10-32	0.190 +0.0000 −0.0054	0.133	0.188	0.313	0.150	0.469	0.031	0.500	0.500	1.125
2,100	12-28	0.216 +0.0000 −0.0062	0.155	0.188	0.313	0.150	0.562	0.031	0.500	0.563	1.125
3,200	¼-28	0.250 +0.0000 −0.0062	0.189	0.250	0.438	0.203	0.625	0.047	0.625	0.625	1.125
4,600	5⁄16-24	0.3125 +0.0000 −0.0066	0.243	0.313	0.500	0.203	0.656	0.047	0.688	0.750	1.125
					Long						
1,600	10-32	0.190 +0.0000 −0.0054	0.133	0.188	0.313	0.150	0.469	0.031	0.500	0.500	2.000
2,100	12-28	0.216 +0.0000 −0.0062	0.155	0.188	0.313	0.150	0.562	0.031	0.500	0.563	2.000
3,200	¼-28	0.250 +0.0000 −0.0062	0.189	0.250	0.438	0.203	0.625	0.047	0.625	0.625	2.000
4,600	5⁄16-24	0.3125 +0.0000 −0.0066	0.243	0.313	0.500	0.203	0.656	0.047	0.688	0.750	2.000
6,100	⅜-24	0.375 +0.0000 −0.0066	0.256	0.375	0.563	0.203	0.843	0.063	0.750	0.875	2.000
8,000	⅜-24	0.375 +0.0000 −0.0066	0.306	0.375	0.563	0.266	0.875	0.063	0.875	0.875	2.000
12,500	7⁄16-20	0.4375 +0.0000 −0.0072	0.362	0.438	0.719	0.344	1.000	0.078	1.063	1.000	2.375
17,500	½-20	0.500 +0.0000 −0.0072	0.425	0.500	0.813	0.406	1.188	0.078	1.188	1.000	2.625

* Threads are American Standard (N.F.), with Class 3 tolerances. N.F. indicates National fine pitch. Finished sizes include plating or protective coating. Tolerances are ± 0.010 except where otherwise indicated.

Pins and Eyebolts

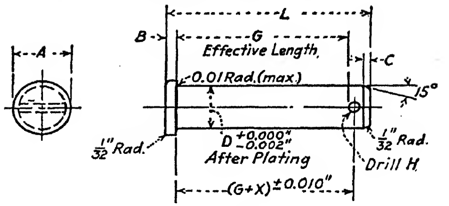
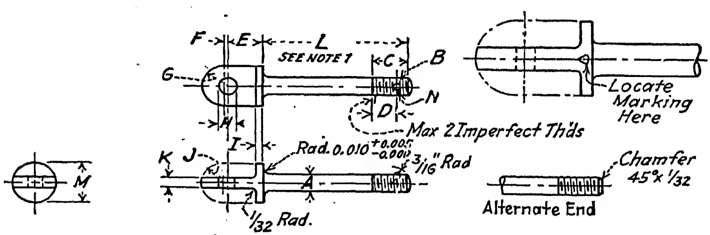


Table 27.—Flathead Pins

Pin size	A	B	C	D	H drill	X	Single shear strength, lb., min.
1/8	1/4	3/64	3/64	0.124	No. 50 (0.070)	0.035	920
3/16	5/16	3/64	3/64	0.186	No. 48 (0.076)	0.038	2,070
1/4	3/8	1/16	1/16	0.248	No. 48 (0.076)	0.038	3,680
5/16	7/16	1/16	5/64	0.311	No. 36 (0.1065)	0.053	5,750
3/8	1/2	1/16	5/64	0.373	No. 36 (0.1065)	0.053	8,290
7/16	9/16	3/32	5/64	0.436	No. 36 (0.1065)	0.053	11,270
1/2	5/8	3/32	5/64	0.497	No. 36 (0.1065)	0.053	14,720
9/16	11/16	3/32	5/64	0.560	No. 28 (0.141)	0.070	18,640
5/8	3/4	3/32	5/64	0.622	No. 28 (0.141)	0.070	23,010
3/4	7/8	3/32	5/64	0.747	No. 28 (0.141)	0.070	33,140
7/8	1 1/16	1/8	3/32	0.871	11/64	0.086	45,100
1	1 3/16	1/8	3/32	0.996	11/64	0.086	58,910

It is recommended that pins of 3/8 to 7/16 in. in diameter be carried up to 3 in. in length only and that pins 1/2 to 1 in. in diameter be carried up to 4 in. in length, as there is no known demand for greater lengths. On pins longer than 2 in., the tolerance should be changed from +0.000, −0.002 to +0.000, −0.003 in. Pins to be ordered in increments of 1/16 in. only.

Physical Properties.—Assembled bolts shall show required minimum tensile strength when tested in tension between the head and the nut. Bolts



shall stand cold-bending in the plain part without fracture through an angle of 180 deg. over a diameter equal to the diameter of the bolt. In short bolts, the test may be made in threaded part, the angle of bend to be through 35 deg.

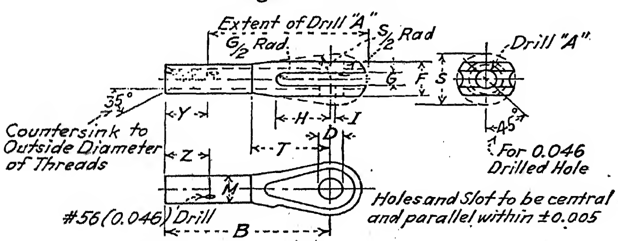
Marking.—Bolts conforming to these specifications shall be marked in some distinctive manner where shown. Bolts conforming entirely to Army-Navy material specifications shall be marked with X. Bolts not marked in either manner will be understood to be made from low-strength material.

Table 28.—Eyebolt Dimensions
(See page 754.)

A,* bolt diam.	Tensile strength, lb., min.	*B*,† thread	*C*, thread length ‡	*D*	*E*	*F*	*G*, radius	*H* +0.010 −0.000	*I*	*J*, radius	*K* ± 0.005	*N*, drill size	*M*
0.1890 +0.0000 −0.0025	2,190	10-32	3/8	1/4	13/32	1/32	7/32	0.188	1/16	7/32	0.094	No. 50 (0.070)	7/16
0.2490 +0.0000 −0.0030	4,070	1/4-28	7/16	9/32	15/32	1/32	1/4	0.188	5/64	1/4	0.125	No. 48 (0.076)	1/2
0.3115 +0.0000 −0.0030	6,550	5/16-24	7/16	21/64	17/32	3/64	5/16	0.250	3/32	5/16	0.188	No. 48 (0.076)	5/8
0.3115 +0.0000 −0.0030	6,550	5/16-24	7/16	21/64	19/32	3/64	11/32	0.313	3/32	11/32	0.188	No. 48 (0.076)	11/16
0.3740 +0.0000 −0.0030	10,100	3/8-24	9/16	13/32	19/32	3/64	3/8	0.375	3/32	3/8	0.188	No. 36 (0.106)	3/4
0.4365 +0.0000 −0.0035	13,620	7/16-20	9/16	29/64	23/32	1/16	7/16	0.375	1/8	7/16	0.250	No. 36 (0.106)	7/8
0.4990 +0.0000 −0.0035	18,580	1/2-20	11/16	9/16	13/16	1/16	1/2	0.4375	1/8	1/2	0.3125	No. 36 (0.106)	1
0.5615 +0.0000 −0.0040	23,000	9/16-18	3/4	39/64	15/16	5/64	19/32	0.500	1/8	19/32	0.375	No. 28 (0.141)	13/16

Standard bolt lengths (*L*) 1/4 to 8 in. by 1/8-in. increments. Tolerances on length, +3/64, −1/64.
* Finished sizes include plating or protective coating.
† Threads are American Standard (N.F.), with Class 3 tolerances. N.F. indicates National fine pitch. Tolerances are ± 0.010 except where otherwise indicated.
‡ Where length of bolt (*L*) is shorter than *C* (thread length), bolt is to be threaded entire length.

Rigid Terminals



Physical Properties.—Rigid terminals shall show the required minimum tensile strength when tension is applied through a stay screwed into the terminal and eyebolt or plate holding the clevis pin in the fork end.

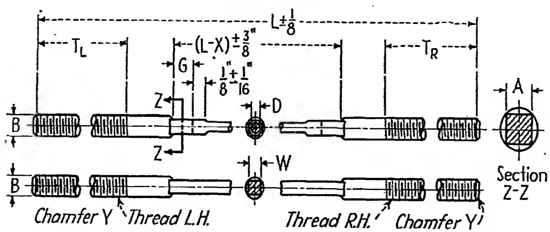
The bend test shall be made on the unbroken forked terminal by bending each side outward from its original position. The terminals from the 6-40 to the 1/2-20 shall withstand a bend of 45 deg.; the 9/16-18 to 3/4-16, a bend of 15 deg., without cracking.

Table 29.—Rigid Terminal Dimensions
(See page 755.)

Ultimate strength lb., min.	Thread*	B ±0.015	D +0.010 −0.000	F +0.010 −0.005	G +0.010 −0.000	H	I	Drill A	Drill for threads	M +0.010 −0.000	S	T	Y ±0.047	Z
1,200	6-40	1.313	0.188	0.250	0.109	0.375	0.031	0.147	No. 33 (0.1130)	0.250	0.375	0.625	0.250	0.313
2,400	10-32	1.532	0.188	0.313	0.150	0.469	0.031	0.199	No. 21 (0.1590)	0.281	0.500	0.719	0.313	0.375
4,200	¼-28	1.813	0.250	0.438	0.203	0.625	0.047	0.261	No. 3 (0.2130)	0.375	0.625	0.875	0.438	0.500
4,600†	5⁄16-24	0.875	0.313	0.500	0.203	0.656	0.047	0.323	0.2703	0.438	0.688	0.938	0.563	0.625
6,900	5⁄16-24	2.000	0.375	0.563	0.203	0.843	0.063	0.323	0.2703	0.453	0.750	1.000	0.563	0.625
10,000	⅜-24	2.250	0.375	0.563	0.266	0.875	0.063	0.386	Q (0.3320)	0.547	0.875	1.125	0.688	0.750
13,700	7⁄16-20	2.500	0.438	0.719	0.344	1.000	0.078	0.453	W (0.3860)	0.625	1.063	1.250	0.750	0.813
18,500	½-20	2.813	0.500	0.813	0.406	1.188	0.078	0.516	0.4492	0.703	1.188	1.438	0.875	0.938
24,000	9⁄16-18	3.125	0.563	0.922	0.453	1.375	0.094	0.578	0.5062	0.796	1.375	1.625	1.000	1.063
29,500	⅝-18	3.375	0.625	1.032	0.516	1.500	0.094	0.640	0.5687	0.875	1.500	1.750	1.125	1.188
42,000	¾-16	4.125	0.750	1.250	0.656	1.938	0.109	0.766	0.6875	1.063	1.813	2.250	1.375	1.438
58,000	⅞-14	4.875	0.875	1.500	0.781	2.313	0.109	0.891	0.8024	1.250	2.125	2.688	1.625	1.688
76,000	1-14	5.750	1.000	1.750	0.906	2.688	0.125	1.016	0.9274	1.438	2.438	3.125	1.875	1.938

* Threads are American Standard (N.F.) with Class 3 tolerances. N.F. indicates National fine pitch. Finished sizes include plating or protective coating. Tolerances are ±0.010, except where otherwise indicated.
† Special for use with 6,900 lb. streamline tie rod and 6,100 lb. internal tie rod of 4,600 lb. rating.

Internal Tie Rods

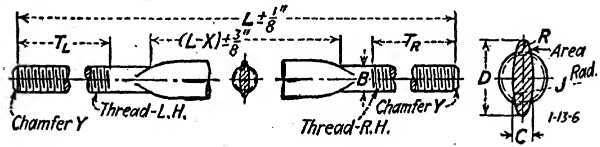


Physical Properties.—Tie rods shall make the specified number of 90-deg. bends without failure, the bends to be back and forth through a total angle of 180 deg.

Table 30.—Internal Tie-rod Dimensions
(See page 756.)

Ultimate strength, lb., min.	Threads*	Pitch, diam.	T_L	T_R	X	A	B	D	W, square	G	Y	K†	No. of 90-deg. bends
1,000	6-40	0.1218 $^{+0.0000}_{-0.0017}$	1¼ $^{+3/64}_{-1/32}$	1¾ $^{+3/64}_{-1/32}$	4	0.115	0.138 $^{+0.0000}_{-0.0048}$	0.101 $^{+0.006}_{-0.000}$	0.089 $^{+0.005}_{-0.000}$	5/16	45° × 1/32	1¼	10
2,100	10-32	0.1697 $^{+0.0000}_{-0.0019}$	1⅜ $^{+1/16}_{-1/32}$	1⅞ $^{+1/16}_{-1/32}$	4¼	0.157	0.190 $^{+0.0000}_{-0.0054}$	0.134 $^{+0.006}_{-0.000}$	0.118 $^{+0.005}_{-0.000}$	⅜	45° × 1/32	1½	10
3,400	¼-28	0.2268 $^{+0.0000}_{-0.0022}$	1⅝ $^{+5/64}_{-1/32}$	2⅛ $^{+5/64}_{-1/32}$	4¾	0.202	0.250 $^{+0.0000}_{-0.0062}$	0.180 $^{+0.007}_{-0.000}$	0.155 $^{+0.005}_{-0.000}$	½	45° × 1/32	1⅞	8
6,100	5/16-24	0.2854 $^{+0.0000}_{-0.0024}$	1¾ $^{+5/64}_{-3/64}$	2¼ $^{+5/64}_{-3/64}$	5	0.250	0.3125 $^{+0.0000}_{-0.0066}$	0.223 $^{+0.008}_{-0.000}$	0.201 $^{+0.005}_{-0.000}$	9/16	45° × 3/64	2⅛	6
8,000	⅜-24	0.3479 $^{+0.0000}_{-0.0024}$	1⅞ $^{+5/64}_{-3/64}$	2⅜ $^{+5/64}_{-3/64}$	5¼	0.300	0.375 $^{+0.0000}_{-0.0066}$	0.274 $^{+0.010}_{-0.000}$	0.236 $^{+0.005}_{-0.000}$	⅝	45° × 3/64	2¼	6
11,500	7/16-20	0.4050 $^{+0.0000}_{-0.0026}$	2⅛ $^{+3/32}_{-3/64}$	2⅝ $^{+3/32}_{-3/64}$	5¾	0.360	0.4375 $^{+0.0000}_{-0.0072}$	0.326 $^{+0.012}_{-0.000}$	0.281 $^{+0.005}_{-0.000}$	⅝	45° × 3/64	2½	6
15,500	½-20	0.4675 $^{+0.0000}_{-0.0026}$	2⅜ $^{+3/32}_{-3/64}$	2⅞ $^{+3/32}_{-3/64}$	6¼	0.420	0.500 $^{+0.0000}_{-0.0072}$	0.377 $^{+0.014}_{-0.000}$	0.327 $^{+0.005}_{-0.000}$	¾	45° × 3/64	2⅞	6

* Threads are American Standard (N.F.) Class 3 fit.
† To determine length of tie rod itself, subtract dimension K from length between clevis pin centers of assembly and specify next longer length when excess is 1/16 in. or more. Lengths are to be specified in ¼-in. increments only. Finished sizes include plating or protective coating.



Streamline Tie Rods.—Tie rods shall make the specified number of 90-deg. bends without failure, the bends to be back and forth through a total angle of 180 deg.

Table 31.—Streamline Tie-rod Dimensions

(See page 757.)

Ultimate strength, lb., min.	Threads*	Pitch diam.		T_L		T_R		X	B		C		D	J	R	Area		Y	K†	No. of 90-deg. bends
1,200	6-40	0.1218	+0.0000 −0.0017	1¼	+3/64 −1/32	1¾	+3/64 −1/32	4	0.138	+0.0000 −0.0048	0.048	+0.0024 −0.0000	0.192	0.288	0.011	0.0071	+0.0007 −0.0000	45° × 1/32	1¼	12
2,400	10-32	0.1697	+0.0000 −0.0019	1⅜	+1/16 −1/32	1⅞	+1/16 −1/32	4¼	0.190	+0.0000 −0.0054	0.064	+0.0032 −0.0000	0.256	0.384	0.014	0.0125	+0.0013 −0.0000	45° × 1/32	1½	12
4,200	¼-28	0.2268	+0.0000 −0.0022	1⅝	+5/64 −1/32	2⅛	+5/64 −1/32	4¾	0.250	+0.0000 −0.0062	0.087	+0.0044 −0.0000	0.348	0.522	0.019	0.0234	+0.0023 −0.0000	45° × 1/32	1⅞	10
6,900	5/16-24	0.2854	+0.0000 −0.0024	1¾	+5/64 −3/64	2¼	+5/64 −3/64	5	0.3125	+0.0000 −0.0066	0.110	+0.0055 −0.0000	0.440	0.660	0.024	0.0376	+0.0038 −0.0000	45° × 3/64	2⅛	8
10,000	⅜-24	0.3479	+0.0000 −0.0024	1⅞	+5/64 −3/64	2⅜	+5/64 −3/64	5¼	0.375	+0.0000 −0.0066	0.135	+0.0068 −0.0000	0.540	0.810	0.030	0.0563	+0.0056 −0.0000	45° × 3/64	2¼	8
13,700	7/16-20	0.4050	+0.0000 −0.0026	2⅛	+3/32 −3/64	2⅝	+3/32 −3/64	5¾	0.4375	+0.0000 −0.0072	0.159	+0.0080 −0.0000	0.636	0.954	0.035	0.0781	+0.0078 −0.0000	45° × 3/64	2½	8
18,500	½-20	0.4675	+0.0000 −0.0026	2⅜	+3/32 −3/64	2⅞	+3/32 −3/64	6¼	0.500	+0.0000 −0.0072	0.183	+0.0092 −0.0000	0.732	1.098	0.040	0.1026	+0.0103 −0.0000	45° × 3/64	2⅞	8
24,000	9/16-18	0.5264	+0.0000 −0.0030	2⅝	+7/64 −3/64	3⅛	+7/64 −3/64	6¾	0.5625	+0.0000 −0.0082	0.209	+0.0100 −0.0000	0.836	1.254	0.045	0.1354	+0.0135 −0.0000	45° × 3/64	3¼	6
29,500	⅝-18	0.5889	+0.0000 −0.0030	2⅞	+7/64 −1/16	3⅜	+7/64 −1/16	7¼	0.625	+0.0000 −0.0082	0.231	+0.0116 −0.0000	0.924	1.386	0.050	0.1655	+0.0165 −0.0000	45° × 3/64	3½	6
42,000	¾-16	0.7094	+0.0000 −0.0032	3¼	+⅛ −1/16	3¾	+⅛ −1/16	8	0.750	+0.0000 −0.0090	0.282	+0.0141 −0.0000	1.128	1.690	0.061	0.2465	+0.0250 −0.0000	45° × 3/64	4⅜	4
58,000	⅞-14	0.8286	+0.0000 −0.0036	3⅞	+⅛ −1/16	4⅜	+⅛ −1/16	9¼	0.875	+0.0000 −0.0098	0.3290	+0.0191 −0.0000	1.315	1.974	0.072	0.336	+0.0336 −0.0000	45° × 1/16	5	1‡
76,000	1-14	0.9536	+0.0000 −0.0036	4½	+⅛ −1/16	5	+⅛ −1/16	10½	1.000	+0.0000 −0.0098	0.3810	+0.0191 −0.0000	1.524	2.285	0.083	0.451	+0.0451 −0.0000	45° × 1/16	6	1‡

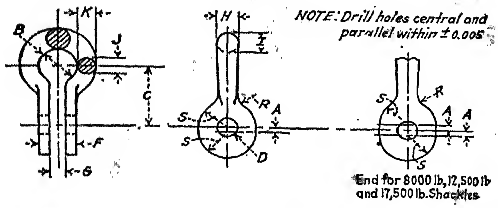
* Threads are American Standard Fine (N.F.) Class 3 fit.

† To determine length of tie rod itself, subtract dimension *K from length between clevis-pin centers of assembly and specify next longer length when excess is* 1/16 in. or more. Lengths to be specified in ¼-in. increments only. Finished sizes include plating or protective coating.

‡ Continuous bend through 180 deg. over radius three times the minor axis.

TERMINAL CONNECTIONS

Shackles



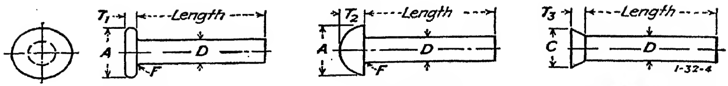
Physical Properties.—Shackles shall show the ultimate strength required when subjected to a tensile test. Shackles, when subjected to a bend test made by opening the shackle and bending flat, shall show no signs of cracking.

Table 32.—Shackle Dimensions

No.	Shackle and cable strength, lb.	*D* +0.010 −0.000	*G* +0.010 −0.000	*F*	*S*	*J*	*K*	*H*	*I*	*A*	*B*	*C*	*R*
8	800	0.188	0.109	0.250	0.250	0.172	0.172	0.172	0.172	0.031	0.250	0.563	0.375
16	1,600	0.188	0.150	0.313	0.250	0.172	0.172	0.172	0.172	0.031	0.250	0.563	0.375
21	2,100	0.188	0.150	0.313	0.281	0.172	0.172	0.172	0.172	0.031	0.250	0.563	0.375
32	3,200	0.250	0.203	0.438	0.313	0.219	0.219	0.250	0.250	0.031	0.375	0.750	0.438
46	4,600	0.313	0.203	0.500	0.375	0.219	0.219	0.281	0.281	0.063	0.438	0.813	0.500
61	6,100	0.375	0.203	0.563	0.375	0.281	0.281	0.313	0.313	0.063	0.500	0.875	0.500
80	8,000	0.375	0.266	0.563	0.406	0.375	0.375	0.438	0.375	0.063	0.438	1.000	0.406
125	12,500	0.438	0.344	0.719	0.531	0.469	0.469	0.594	0.469	0.094	0.625	1.125	0.750
175	17,500	0.500	0.406	0.813	0.625	0.563	0.563	0.688	0.563	0.125	0.625	0.120	0.500

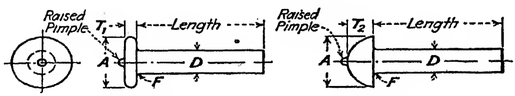
Finished sizes include plating or protective coating. Tolerances are ± 0.010 except where otherwise indicated.

Rivets

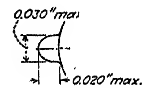


FLAT HEAD ROUND HEAD COUNTERSINK HEAD

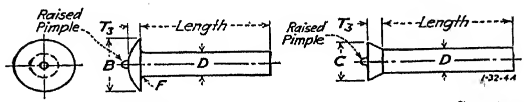
Aluminum Alloy Type



FLAT HEAD ROUND HEAD



PIMPLE



Brazier head. Countersunk head.

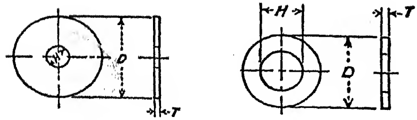
Table 33.—Aluminum and Aluminum Alloy Rivet Dimensions

Body diam., D, in.	1/16 +0.003 −0.001	3/32 +0.003 −0.001	1/8 +0.0035 −0.001	5/32 +0.004 −0.001	3/16 +0.004 −0.001	1/4 +0.004 −0.001	5/16 +0.004 −0.001	3/8 +0.004 −0.001
A	1/8 ±0.006	3/16 ±0.009	1/4 ±0.012	5/16 ±0.016	3/8 ±0.019	1/2 ±0.025	5/8 ±0.031	3/4 ±0.037
B	5/32 ±0.008	15/64 ±0.012	5/16 ±0.016	25/64 ±0.020	15/32 ±0.023	5/8 ±0.031	25/32 ±0.039	15/16 ±0.047
C	0.117 ±0.006	0.168 ±0.008	0.226 ±0.011	0.282 ±0.014	0.339 ±0.017	0.452 ±0.023	0.565 ±0.028	0.678 ±0.029
T_1	0.025 ±0.005	0.038 ±0.005	0.050 ±0.005	0.062 ±0.005	0.075 ±0.005	0.100 ±0.005	0.125 ±0.005	0.150 ±0.007
T_2	0.047 ±0.005	0.070 ±0.005	0.094 ±0.005	0.117 ±0.005	0.141 ±0.007	0.188 ±0.009	0.234 ±0.012	0.281 ±0.014
T_3	1/32 ±0.005	3/64 ±0.005	1/16 ±0.005	5/64 ±0.005	3/32 ±0.005	1/8 ±0.006	5/32 ±0.008	3/16 ±0.009

All rivets except countersunk head to have fillet F under the head, minimum radius 0.01 in. Maximum radius not to interfere with heading.

Heads of all rivets made of aluminum alloy S.A.E. No. 26 to have raised pimple for identification.

Washers



Large. Small.

Table 34.—Plain Washers

Nominal bolt size	H	Large		Small	
		D	T	D	T
No. 8	11/64	.....	...	3/8	1/32
No. 10	13/64	7/8	1/16	7/16	1/16
1/4	17/64	1 1/8	1/16	1/2	1/16
5/16	21/64	1 3/8	1/16	9/16	1/16
3/8	25/64	1 5/8	1/16	5/8	1/16
7/16	29/64	1 13/16	1/10	3/4	1/16
1/2	33/64	2	1/10	7/8	1/16
9/16	37/64	2 3/16	1/8	1 1/16	1/16
5/8	41/64	2 3/8	1/8	1 3/16	1/16
3/4	49/64	.....	...	1 5/16	3/32
7/8	57/64	.....	...	1 1/2	3/32
1	1 1/64	.....	...	1 3/4	3/32

Control Cable Pulleys

These pulleys or sheaves are for use with aircraft control cables. Where the smaller size pulleys are used, they should be selected in accordance with the note following the table, depending on the amount of bend there will be in the cables in passing over the pulleys.

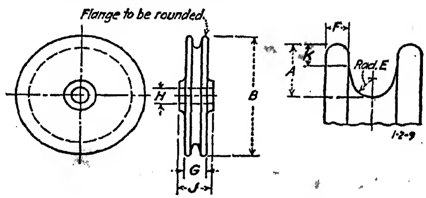


Table 35.—Control Cable Pulleys

No.	Cable size	A −0.000	B ±0.010	E	Design load, lb., max.	F	G*	H +0.0000 −0.0005	J +0.000 −0.005	K ±0.001
1A†	1/16, 5/64, 3/32	0.139 +0.010	1 1/4	0.052 +0.003 −0.000	200	0.060 ±0.005	0.250 +0.000 −0.010	0.1900	0.297	0.040
2A	1/16, 5/64, 3/32	0.139 +0.010	2 1/2	0.052 +0.003 −0.000	500	0.060 ±0.005	0.250 +0.000 −0.010	0.1900	0.297	0.040
3A	1/8, 5/32, 3/16	0.245 +0.012	2	0.109 +0.003 −0.000	1,200	0.086 ±0.006	0.422 +0.000 −0.012	0.2500	0.484	0.086
4A	1/8, 5/32, 3/16	0.245 +0.012	3 1/2	0.109 +0.003 −0.000	1,200	0.086 ±0.006	0.422 +0.000 −0.012	0.2500	0.484	0.086
5A	3/16, 7/32, 1/4	0.313 +0.015	5	0.140 +0.005 −0.000	2,000	0.092 ±0.007	0.500 ±0.007	0.3750	0.620	0.092
6A	3/16, 7/32, 1/4	0.313 +0.015	6	0.140 +0.005 −0.000	2,500	0.092 ±0.007	0.500 ±0.007	0.3750	0.620	0.092
10A	5/16, 3/8, 7/16	0.531 +0.015	10	0.234 ±0.003	5,000	0.170 ±0.010	0.875 ±0.010	0.5000	1.125	0.170
14A	7/16, 1/2	0.625 +0.015	14 1/2	0.281 ±0.003	10,000	0.190 ±0.010	1.000 ±0.010	0.6250	1.245	0.190

* Hub may be added to pulley where width of outer race of bearing is greater than G.
† Pulleys 1A and 3A shall not be installed on frequently used aircraft controls to bend the cable more than 30 deg. from a straight line.

Steel Thimbles

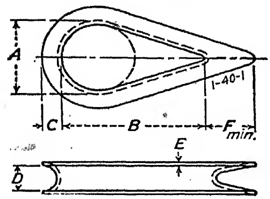


Table 36.—Steel Thimbles

Diam. of cable		A	B	C $+\frac{1}{64}$ -0	D $+\frac{1}{64}$ -0	E	F
Nominal	Decimal						
1/16, 5/64, 3/32	0.062	0.35	0.70	0.07	0.09	0.032 ± 0.003	3/16
3/32, 7/64, 1/8	0.094	0.35	0.70	0.07	0.13	0.032 ± 0.003	7/32
5/32	0.156	0.40	0.80	0.10	0.17	0.032 ± 0.003	7/32
3/16	0.187	0.50	1.00	0.135	0.21	0.032 ± 0.003	5/16
7/32	0.219	0.60	1.20	0.15	0.24	0.032 ± 0.003	3/8
1/4	0.250	0.70	1.40	0.17	0.25	0.032 ± 0.003	13/32
9/32	0.281	0.80	1.60	0.198	0.30	0.040 ± 0.004	13/32
5/16	0.312	0.90	1.80	0.21	0.33	0.040 ± 0.004	7/16
3/8	0.375	1.00	2.00	0.26	0.39	0.060 ± 0.004	5/8
7/16	0.437	1.125	2.25	0.33	0.46	0.080 ± 0.004	13/16
1/2	0.500	1.25	2.50	0.40	0.52	0.080 ± 0.004	1

The thimbles shall be galvanized by either the electrical or hot-dip process. Tolerances, ± 1/64 except where otherwise noted.

Bolts and Nuts

Plain Hexagon Head Steel Bolts.—Bolts shall show required minimum strength when assembled with a suitable nut and tested in tension between head and nut. They shall stand cold bending in the plain part without fracture through an angle of 180 deg. over a diameter equal to the diameter of the bolt. In short bolts, the test may be made in threaded part, the angle of bend to be through 35 deg.

Bolts conforming to the following specifications shall be marked in some distinctive manner where shown. Bolts conforming entirely to Army-Navy material specifications shall be marked with "X". Bolts not marked in either manner will be understood to be made from low strength material.

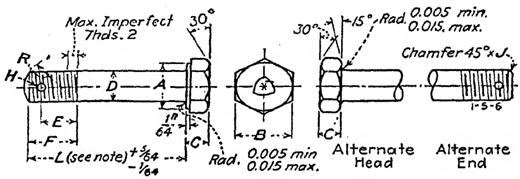


Table 37.—Dimensions

Nominal bolt size	Threads per in.*	A	B −0.010	C	D† +0.0000	E	F	H	J	R	Tensile strength, lb., min.
0.1900 (No. 10)	32	3/8	0.3750+0.002	1/8	0.1890−0.0025	1/4	[illegible]	0.070	[illegible]	[illegible]	2,430
0.2500 (1/4)	28	7/16	0.4375+0.002	5/32	0.2490−0.0030	9/32	[illegible]	0.070	[illegible]	[illegible]	4,430
0.3125 (5/16)	24	[illegible]	0.5000−0.002	[illegible]	0.3115−0.0030	21/64	[illegible]	0.070	[illegible]	[illegible]	7,140
0.3750 (3/8)	24	[illegible]	0.5625−0.0025	[illegible]	0.3740−0.0030	13/32	[illegible]	0.106	[illegible]	[illegible]	10,830
0.4375 (7/16)	20	[illegible]	0.6250−0.0025	[illegible]	0.4365−0.0035	29/64	[illegible]	0.106	[illegible]	[illegible]	14,040
0.5000 (1/2)	20	[illegible]	0.7500−0.0025	[illegible]	0.4990−0.0035	9/16	[illegible]	0.106	[illegible]	[illegible]	19,740
0.5625 (9/16)	18	[illegible]	0.8750−0.0025	[illegible]	0.5615−0.0040	39/64	[illegible]	0.141	[illegible]	[illegible]	25,080
0.6250 (5/8)	18	[illegible]	0.9375−0.0025	[illegible]	0.6240−0.0040	11/16	[illegible]	0.141	[illegible]	[illegible]	31,640
0.7500 (3/4)	16	1 [illegible]	1.0625−0.003	[illegible]	0.7490−0.0045	13/16	[illegible]	0.141	[illegible]	[illegible]	46,180
0.8750 (7/8)	14	1 [illegible]	1.2500−0.003	[illegible]	0.8740−0.0050	29/32	1 [illegible]	0.141	[illegible]	[illegible]	63,100
1.0000 (1)	14	1 [illegible]	1.4375−0.003	[illegible]	0.9990−0.0055	1	1 [illegible]	0.141	[illegible]	1	84,300

* Threads are American Standard Fine (N.F.), with Class 3 tolerances.
† Finished sizes include plating or protective coating. Bolt lengths 3/8 to 8 in. by 1/8-in. increments. Where L is shorter than F, bolt is to be threaded entire length.

Plain Hexagon Nuts.—Nuts shall be manufactured from bar steel having the following physical properties:

Tensile strength, lb. per sq. in., min.	70,000
Yield point, lb. per sq. in., min.	50,000
Elongation, in 2 in., per cent, min.	10
Reduction of area, per cent, min.	40

Test specimens for the flattening test shall be selected at random from the lot submitted for inspection. The nuts shall withstand being decreased in over-all diameter or distance between flats by an amount equal to 10 per cent of the nominal bolt diameter without visible cracks on the inside or outside of the nut. The flattening shall be done by steadily pressing the nuts edgewise in a vise or testing machine until the specified reduction has been made.

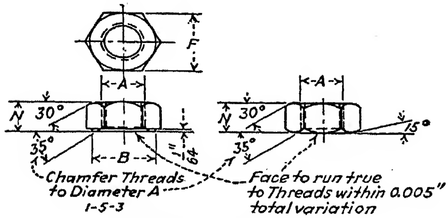


Table 38.—Dimensions

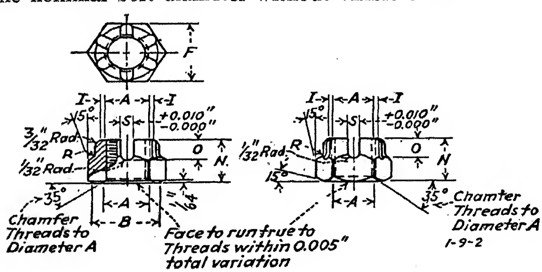
A*, nominal size	Threads† per in.	B, diam. of washer face ±0.010	F, width across flats −0.010	N‡	
				Full strength ±0.010	Thin and check ±0.010
0.1900 (No. 10)	32	3/8	0.375 + 0.002	9/64	...
0.2500-1/4	28	7/16	0.4375 + 0.002	3/16	1/8
0.3125-5/16	24	1/2	0.500 + 0.002	15/64	5/32
0.3750-3/8	24	9/16	0.5625 + 0.0025	9/32	3/16
0.4375-7/16	20	5/8	0.625 + 0.0025	21/64	7/32
0.500-1/2	20	3/4	0.750 + 0.0025	3/8	1/4
0.5625-9/16	18	7/8	0.875 + 0.0025	27/64	9/32
0.6250-5/8	18	1	1.000 + 0.0025	15/32	5/16
0.7500 (3/4)	16	1 1/8	1.125 + 0.003	9/16	3/8
0.8750 (7/8)	14	1 5/16	1.3125 + 0.003	21/32	7/16
1.0000 (1)	14	1 1/2	1.5 + 0.003	3/4	1/2

* Finished sizes include plating or protective coating.
† Threads are American Standard Fine (N.F.), with Class 3 tolerances.
‡ For full-strength nuts, $N = 3A/4$. For check nuts and thin nuts for shear bolts 1/4 in. in diameter and larger, $N = A/2$.

Castle Hexagon Nuts.—Nuts shall be manufactured from bar steel having the following physical properties:

Tensile strength, lb. per sq. in., min	70,000
Yield point, lb. per sq. in., min	50,000
Elongation in 2 in., per cent, min	10
Reduction of area, per cent min	40

Test specimens for the flattening test shall be selected at random from the lot submitted for inspection. The nuts shall withstand being decreased in over-all diameter or distance between flats by an amount equal to 10 per cent of the nominal bolt diameter without visible cracks on the inside or



outside of the nut. The flattening shall be done by steadily pressing the nuts edgewise in a vise or testing machine until the specified reduction has been made.

Table 39.—Dimensions

A, bolt size threads per in.*	*B*, diameter of washer face	*F*, width across flats − 0.010	*N* ±0.010	*S* +0.010 −0.000	*O*† ±0.010	*R* ±0.010	*I*‡ ±0.010
0.1900 (No. 10)-32	3/8	0.375 + 0.002	1/4	5/64	9/64	3/32	1/64
0.2500 (1/4)-28	7/16	0.4375 + 0.002	9/32	5/64	5/32	3/32	1/32
0.3125 (5/16)-24	1/2	0.500 + 0.002	21/64	5/64	5/32	3/32	1/32
0.3750 (3/8)-24	9/16	0.5625 + 0.0025	13/32	1/8	3/16	3/32	1/32
0.4375 (7/16)-20	5/8	0.625 + 0.0025	29/64	1/8	3/16	3/32	3/64
0.5000 (1/2)-20	3/4	0.750 + 0.0025	9/16	1/8	13/64	1/8	3/64
0.5625 (9/16	7/8	0.875 + 0.0025	39/64	5/32	7/32	5/32	3/64
0.6250 (5/8)-18	1	1.000 + 0.0025	11/16	5/32	7/32	5/32	3/64
0.7500 (3/4)-16	1 1/8	1.125 + 0.003	13/16	5/32	1/4	3/16	1/16
0.8750 (7/8)-14	1 5/16	1.3125 + 0.003	29/32	5/32	1/4	3/16	1/16
1.0000 (1)-14	1 1/2	1.5 + 0.003	1	5/32	1/4	3/16	1/16

* Finished sizes include plating or protective coating.
† Also depth of slot.
‡ Distance from *A* to beginning of 3/32-in. radius, whose center is floating to satisfy curve.
All threads are American Standard Fine (N.F.), with Class 3 tolerances.

Slotted Shear Nuts

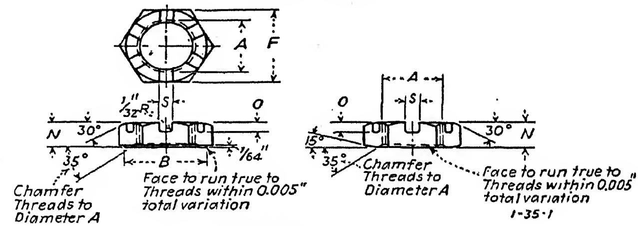


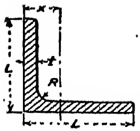
Table 40.—Dimensions

Bolt size *A*, threads per in.*	*B*, diam. of washer face	*F*, width across flats −0.010	*N*	*S* +0.010 −0.000	*O*
0.1640 (No. 8)-36	11/32	0.344 + 0.002	5/32	5/64	5/64
0.1900 (No. 10)-32	3/8	0.375 + 0.002	3/16	5/64	3/32
0.2500 (1/4)-28	7/16	0.4375 + 0.002	3/16	5/64	3/32
0.3125 (5/16)-24	1/2	0.500 + 0.002	3/16	5/64	3/32
0.3750 (3/8)-24	9/16	0.5625 + 0.0025	7/32	1/8	7/64
0.4375 (7/16)-20	5/8	0.625 + 0.0025	7/32	1/8	7/64
0.5000 (1/2)-20	3/4	0.750 + 0.0025	1/4	1/8	7/64
0.5625 (9/16)-18	7/8	0.875 + 0.0025	5/16	5/32	1/8
0.6250 (5/8)-18	1	1.000 + 0.0025	5/16	5/32	1/8
0.7500 (3/4)-16	1 1/8	1.125 + 0.003	3/8	5/32	1/8
0.8750 (7/8)-14	1 5/16	1.3125 + 0.003	7/16	5/32	1/8
1.0000 (1)-14	1 1/2	1.500 + 0.003	1/2	5/32	1/8
1.2500 (1 1/4)-12	1 7/8	1.875 + 0.003	5/8	5/32	5/32

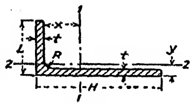
* Finished sizes include plating or protective coating. All threads are American Standard Fine (N.F.). Class 3 tolerances. Tolerances are ±0.010 in. except where otherwise indicated.

STRUCTURAL MEMBERS

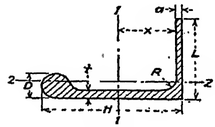
Extruded Shapes—Aluminum Alloy



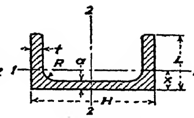
See Table 41.



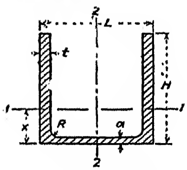
See Table 41.



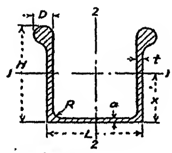
See Table 41.



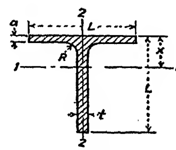
See Table 42.



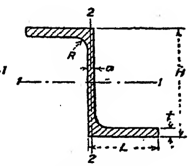
See Table 42.



See Table 42.



See Table 43.



See Table 44.

Table 41.—Extruded Angles

Size	t	L	R	x	Area	Moment of inertia	Section modulus	Weight per ft.	Radius of gyration	Least radius of gyration
Equal Angles										
5/8	0.063	5/8	0.063	0.181	0.0763	0.002843	0.006235	0.092	0.194	0.123
3/4	0.075	3/4	0.075	0.215	0.1081	0.005711	0.01068	0.130	0.231	0.147
7/8	0.088	7/8	0.088	0.253	0.1488	0.01083	0.01723	0.178	0.272	0.172
1	0.100	1	0.100	0.287	0.1922	0.01805	0.0253	0.231	0.309	0.195
1 1/4	0.125	1 1/4	0.125	0.359	0.3003	0.04404	0.04941	0.360	0.386	0.244
1 1/2	0.150	1 1/2	0.150	0.431	0.4324	0.09138	0.08539	0.520	0.463	0.293
2	0.200	2	0.200	0.574	0.7688	0.2888	0.2024	0.922	0.617	0.391

Table 41.—Extruded Angles (*Continued*)

Unequal Angles

Size	a	D	H	L	R	t	x	y	Area	I_{1-1}	S_{1-1}	K_{1-1}	I_{2-2}	S_{2-2}	K_{2-2}	Weight per ft.
½ × 1	....	....	1	½	0.063	0.063	0.357	0.108	0.09216	0.009766	0.015007	0.326	0.001700	0.004290	0.136	0.111
⅝ × 1¼	....	....	1¼	⅝	0.078	0.078	0.442	0.133	0.14127	0.022943	0.028484	0.403	0.003994	0.008142	0.168	0.170
¾ × 1½	....	....	1½	¾	0.094	0.094	0.533	0.161	0.20517	0.048415	0.049861	0.486	0.008429	0.014253	0.203	0.246
⅞ × 1¾	....	....	1¾	⅞	0.109	0.109	0.618	0.186	0.27488	0.087529	0.077739	0.564	0.015238	0.022222	0.235	0.031
1 × 2	....	....	2	1	0.125	0.125	0.709	0.211	0.36281	0.151297	0.117239	0.646	0.026340	0.033513	0.270	0.435
1¼ × 2½	....	....	2½	1¼	0.156	0.156	0.884	0.267	0.56508	0.367230	0.227898	0.806	0.063932	0.065146	0.337	0.678

Bulb Angles

Size	a	D	H	L	R	t	x	y	Area	I_{1-1}	S_{1-1}	K_{1-1}	I_{2-2}	S_{2-2}	K_{2-2}	Weight per ft.
1⁵⁄₁₆	0.063	0.188	1⁵⁄₁₆	⅝	0.094	0.063	0.367	....	0.12518	0.01289	0.02231	0.321	....	....	....	0.150
1⅛	0.063	0.225	1⅛	¾	0.112	0.075	0.451	....	0.17111	0.02475	0.03671	0.381	....	....	....	0.205
1⁵⁄₁₆	0.063	0.264	1⁵⁄₁₆	⅞	0.132	0.088	0.630	....	0.19700	0.04333	0.06273	0.469	0.005196	....	....	0.236
1½	0.070	0.300	1½	1	0.150	0.100	0.716	....	0.2511	0.07222	0.09211	0.533	0.00866	....	....	0.305
1⅞	0.088	0.375	1⅞	1¼	0.188	0.125	0.895	....	0.3975	0.17621	0.17989	0.666	0.02113	....	....	0.477
2¼	0.105	0.450	2¼	1½	0.225	0.150	0.074	....	0.5724	0.56560	0.31087	0.799	0.04384	....	....	0.687
3	0.140	0.600	3	2	0.300	0.200	1.432	....	1.0176	1.15549	0.73688	1.066	1.03856	....	....	1.220

I = moment of inertia; K = radius of gyration; S = section modulus.

Table 42.—Extruded Channels

Shallow

Size	a	D	H	L	R	t	x	y	Area	I_{1-1}	S_{1-1}	K_{1-1}	I_{2-2}	S_{2-2}	K_{2-2}	Weight per ft.
¾	0.063	....	¾	⅜	0.063	0.063	0.117	....	0.08902	0.001119	0.004308	0.112	0.007195	0.019035	0.092	0.107
⅞	0.063	....	⅞	⁷⁄₁₆	0.063	0.063	0.132	....	0.10490	0.001836	0.005950	0.132	0.011823	0.026808	0.336	9.126
⅞	0.063	....	⅞	⁷⁄₁₆	0.088	0.088	0.050	....	0.12567	0.002277	0.007920	0.135	0.014113	0.033013	0.339	0.151
1	0.070	....	1	½	0.100	0.100	0.171	....	0.16030	0.003775	0.011470	0.153	0.023909	0.01782	0.386	0.192
1¼	0.088	....	1¼	⅝	0.125	0.125	0.214	....	0.25047	0.009211	0.022401	0.192	0.058338	0.09339	0.482	0.301
1½	0.105	....	1½	¾	0.150	0.150	0.257	....	0.36067	0.028322	0.038711	0.230	0.121039	0.16139	0.579	0.433

Deep

Size	a	D	H	L	R	t	x	y	Area	I_{1-1}	S_{1-1}	K_{1-1}	I_{2-2}	S_{2-2}	K_{2-2}	Weight per ft.
1	0.063	....	1	⅞	0.063	0.077	0.317	....	0.20016	0.02208	0.03194	0.332	0.02382	0.05402	0.345	0.240
1¼	0.078	....	1¼	1³⁄₃₂	0.078	0.094	0.392	....	0.30682	0.05186	0.06063	0.411	0.05597	0.10253	0.427	0.368
1½	0.094	....	1½	1⁵⁄₁₆	0.094	0.113	0.473	....	0.44560	0.10944	0.10613	0.495	0.11811	0.17948	0.515	0.535
1¾	0.109	....	1¾	1¹⁷⁄₃₂	0.109	0.131	0.548	....	0.59916	0.19785	0.16546	0.574	0.21352	0.27984	0.597	0.719
2	0.125	....	2	1¾	0.125	0.150	0.629	....	0.78797	0.34199	0.24953	0.659	0.36098	0.42202	0.685	0.946

I = moment of inertia; K = radius of gyration; S = section modulus.

Table 42.—Extruded Channels (*Continued*)

Bulb

Size	a	D	H	L	R	t	x	Area	$I_{1\text{-}1}$	$S_{1\text{-}1}$	$K_{1\text{-}1}$	$I_{2\text{-}2}$	$S_{2\text{-}2}$	$K_{2\text{-}2}$	Weight per ft
1	1/16	3/16	1	7/8	1/16	1/16	0.464	0.21671	0.028629	0.05049	0.363	0.033059	0.060735	0.390	0.260
1¼	5/64	15/64	1¼	1 3/32	5/64	5/64	0.574	0.33219	0.067255	0.09584	0.450	0.077663	0.115288	0.484	0.399
1½	0.070	9/32	1½	1 5/16	3/32	3/32	0.728	0.45594	0.13117	0.15505	0.537	0.16108	0.20755	0.594	0.547
1¾	0.082	21/64	1¾	1 17/32	7/64	7/64	0.844	0.61306	0.23715	0.24174	0.622	0.29121	0.32359	0.689	0.736
2	3/32	3/8	2	1¾	1/8	1/8	0.968	0.80625	0.40992	0.36457	0.714	0.50337	0.48802	0.790	0.968

I = moment of inertia; K = radius of gyration; S = section modulus.

Table 43.—Extruded Tees

Size	a	D	H	L	R	t	x	Area	$I_{1\text{-}1}$	$S_{1\text{-}1}$	$K_{1\text{-}1}$	$I_{2\text{-}2}$	$S_{2\text{-}2}$	$K_{2\text{-}2}$	Weight per ft
¾	0.063	....	....	¾	0.075	0.075	0.224	0.1012	0.005565	0.01057	0.235	0.002246	0.00599	0.149	0.121
1	0.070	....	....	1	0.100	0.100	0.314	0.1673	0.01694	0.02171	0.318	0.006935	0.01387	0.204	0.201
1¼	0.088	....	....	1¼	0.125	0.125	0.393	0.2614	0.04133	0.04826	0.398	0.01692	0.02709	0.254	0.314
1½	0.105	....	....	1½	0.150	0.150	0.472	0.3764	0.08576	0.08340	0.477	0.03511	0.04681	0.305	0.452
1¾	0.123	....	....	1¾	0.175	0.175	0.550	0.5124	0.15888	0.13242	0.557	0.06504	0.07433	0.356	0.615
2	0.140	....	....	2	0.200	0.200	0.692	0.6692	0.27104	0.19768	0.636	0.11096	0.11096	0.407	0.803

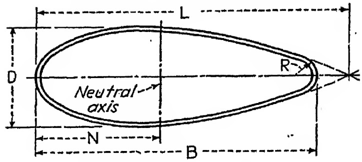
I = moment of inertia; K = radius of gyration; S = section modulus.

Table 44.—Extruded Zees

Size	a	D	H	L	R	t	x	Area	$I_{1\text{-}1}$	$S_{1\text{-}1}$	$K_{1\text{-}1}$	$I_{2\text{-}2}$	$S_{2\text{-}2}$	$K_{2\text{-}2}$	Weight per ft
7/8	0.063	....	7/8	½	3/32	0.063	.....	0.1150	0.01340	0.03038	0.341	0.00446	0.01012	0.197	0.138
1	0.063	....	1	9/16	0.125	0.080	.....	0.1510	0.02375	0.04713	0.397	0.00824	0.01538	0.234	0.181
1¼	0.063	....	1¼	11/16	0.125	0.100	.....	0.2132	0.05500	0.08730	0.508	0.01947	0.02943	0.302	0.256
1½	0.075	....	1½	0.825	0.150	0.120	.....	0.3022	0.11049	0.14736	0.604	0.03911	0.04968	0.360	0.363
1¾	0.088	....	1¾	0.963	0.175	0.140	.....	0.4160	0.20952	0.23780	0.709	0.07416	0.08017	0.422	0.499
2	0.100	....	2	1.10	0.200	0.160	.....	0.5372	0.34920	0.34920	0.806	0.12360	0.11772	0.480	0.645
2½	0.125	....	2½	1⅜	0.250	0.200	.....	0.8394	0.85206	0.68199	1.007	0.30160	0.22991	0.600	1.007
3	0.150	....	3	1.65	0.300	0.240	.....	1.2087	1.76785	1.17855	1.209	0.62575	0.39730	0.720	1.450

I = moment of inertia; K = radius of gyration; S = section modulus.

Streamline Steel Tubing



Developed section of tube.

Table 45.—Streamline Tubing Dimensions

Round tubing, diam., in.	*D*	*B*	*L*	*N*	*R*
2	1.143	2.697	2.857	1.286	0.217
2¼	1.286	3.034	3.214	1.446	0.244
2½	1.429	3.371	3.571	1.607	0.271
2¾	1.571	3.708	3.928	1.768	0.299
3	1.714	4.046	4.286	1.929	0.326
3¼	1.857	4.383	4.643	2.089	0.353
3½	2.000	4.720	5.000	2.250	0.380
3¾	2.143	5.057	5.357	2.411	0.407
4	2.286	5.394	5.714	2.571	0.434
4¼	2.428	5.731	6.071	2.732	0.461
4½	2.571	6.068	6.428	2.893	0.489
4¾	2.714	6.405	6.785	3.053	0.516
5	2.857	6.743	7.143	3.214	0.543

D (max. width of section) $= 0.5714 \times$ diam. of round tube; $L = 2.5 \times D$; $B = 0.944 \times L$; $R = 0.19 \times D$; $N = 0.45 \times L$.

Table 46.—Progressive Section Width Dimensions—Streamline Tubing
(Round Tubing Diam. In.)

2		2¼		2½		2¾		3		3¼		3½		3¾		4		4¼		4½		4¾		5	
A*	B†	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.036	0.297	0.040	0.334	0.045	0.371	0.049	0.409	0.054	0.446	0.058	0.483	0.063	0.520	0.067	0.557	0.071	0.594	0.076	0.631	0.080	0.669	0.085	0.706	0.089	0.743
0.071	0.424	0.080	0.477	0.089	0.530	0.098	0.583	0.107	0.636	0.116	0.689	0.125	0.742	0.134	0.795	0.143	0.848	0.152	0.901	0.161	0.954	0.170	1.007	0.179	1.060
0.143	0.600	0.161	0.675	0.179	0.750	0.196	0.825	0.214	0.900	0.232	0.975	0.250	1.050	0.268	1.125	0.286	1.200	0.304	1.275	0.321	0.350	0.339	1.425	0.357	1.500
0.214	0.727	0.241	0.818	0.268	0.909	0.295	0.999	0.321	1.090	0.348	1.181	0.375	1.272	0.402	1.363	0.429	1.454	0.455	1.544	0.482	1.635	0.509	1.726	0.536	1.817
0.286	0.823	0.321	0.926	0.357	1.029	0.393	1.131	0.429	1.234	0.464	1.337	0.500	1.440	0.536	1.543	0.571	1.646	0.607	1.748	0.643	1.851	0.679	1.954	0.714	2.057
0.357	0.897	0.402	1.009	0.446	1.121	0.491	1.234	0.536	1.346	0.580	1.458	0.625	1.570	0.670	1.682	0.714	1.794	0.759	1.906	0.804	2.018	0.848	2.131	0.893	2.243
0.429	0.955	0.482	1.075	0.536	1.194	0.589	1.314	0.643	1.433	0.696	1.553	0.750	1.672	0.804	1.791	0.857	1.911	0.911	2.030	0.964	2.150	1.018	2.269	1.071	2.388
0.500	1.003	0.562	1.129	0.625	1.254	0.688	1.380	0.750	1.505	0.812	1.630	0.875	1.756	0.938	1.881	1.000	2.007	1.062	2.132	1.125	2.258	1.187	2.383	1.250	2.508
0.571	1.041	0.643	1.171	0.714	1.301	0.786	1.432	0.857	1.561	0.929	1.692	1.000	1.822	1.071	1.952	1.143	2.082	1.214	2.212	1.286	2.342	1.357	2.473	1.429	2.603
0.714	1.096	0.804	1.233	0.893	1.370	0.982	1.507	1.071	1.644	1.161	1.781	1.250	1.918	1.339	2.055	1.429	2.192	1.518	2.329	1.607	2.466	1.696	2.603	1.786	2.740
0.857	1.129	0.964	1.270	1.071	1.411	1.179	1.553	1.286	1.694	1.393	1.835	1.500	1.976	1.607	2.117	1.714	2.258	1.821	2.399	1.928	2.540	2.036	2.682	2.143	2.823
1.000	1.143	1.125	1.286	1.250	1.429	1.375	1.571	1.500	1.714	1.625	1.857	1.750	2.000	1.875	2.143	2.000	2.283	2.125	2.428	2.250	2.571	2.375	2.714	2.500	2.857
1.143	1.137	1.286	1.279	1.429	1.421	1.571	1.564	1.714	1.706	1.857	1.848	2.000	1.990	2.143	2.132	2.286	2.274	2.428	2.416	2.571	2.558	2.714	2.701	2.857	2.843
1.286	1.119	1.446	1.259	1.607	1.399	1.768	1.538	1.929	1.678	2.089	1.818	2.250	1.958	2.411	2.098	2.571	2.238	2.732	2.377	2.893	2.517	3.053	2.657	3.214	2.797
1.429	1.086	1.607	1.221	1.786	1.357	1.964	1.493	2.143	1.629	2.321	1.764	2.500	1.900	2.678	2.036	2.857	2.171	3.036	2.307	3.214	2.443	3.393	2.578	3.571	2.714
1.571	1.040	1.768	1.170	1.964	1.300	2.161	1.430	2.357	1.560	2.553	1.690	2.750	1.820	2.946	1.950	3.143	2.080	3.339	2.210	3.536	2.340	3.732	2.470	3.928	2.600
1.714	0.984	1.929	1.107	2.143	1.230	2.357	1.353	2.571	1.476	2.786	1.599	3.000	1.722	3.214	1.845	3.428	1.968	3.643	2.091	3.857	2.214	4.071	2.337	4.286	2.460
1.857	0.915	2.089	1.030	2.321	1.144	2.553	1.259	2.786	1.373	3.018	1.488	3.250	1.602	3.482	1.716	3.714	1.831	3.946	1.945	4.178	2.000	4.410	2.174	4.643	2.288
2.000	0.837	2.250	0.941	2.500	1.046	2.750	1.150	3.000	1.255	3.250	1.359	3.500	1.464	3.750	1.569	4.000	1.673	4.250	1.778	4.500	1.882	4.750	1.987	5.000	2.091
2.143	0.746	2.411	0.840	2.678	0.933	2.946	1.026	3.214	1.119	3.482	1.213	3.750	1.306	4.018	1.399	4.286	1.492	4.553	1.586	4.821	1.679	5.089	1.772	5.357	1.866
2.286	0.642	2.571	0.723	2.857	0.803	3.143	0.883	3.428	0.963	3.714	1.044	4.000	1.124	4.286	1.204	4.571	1.285	4.857	1.365	5.143	1.445	5.428	1.525	5.714	1.606
2.429	0.527	2.732	0.593	3.036	0.659	3.339	0.724	3.643	0.790	3.946	0.856	4.250	0.922	4.553	0.988	4.857	1.054	5.160	1.119	5.464	1.185	5.768	1.251	6.071	1.317
2.571	0.386	2.893	0.435	3.214	0.483	3.536	0.531	3.857	0.579	4.178	0.628	4.500	0.676	4.821	0.724	5.143	0.773	5.464	0.821	5.785	0.869	6.107	0.917	6.428	0.966
2.714	0.217	3.053	0.244	3.393	0.271	3.732	0.299	4.071	0.326	4.410	0.353	4.750	0.380	5.089	0.407	5.428	0.434	0.767	0.461	6.107	0.489	6.446	0.516	6.785	0.543

* A = distance from nose. † B = section width.

Table 47.—Round Tubing Sizes

Tubing walls B.W.G.	Outside diam.—in.																																	
	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8	3	3 1/4	3 1/2	3 3/4	4	4 1/4	4 1/2	4 3/4	5
Aluminum Alloy																																		
No. 24 (0.022)	..	X	X	X	X	X																												
22 (0.028)	..	X	X	X	X	X	X	X	X	X																								
21 (0.032)	..	..	..	..	..	X	X	X	X	X	X	X	..	..	..	..	..	S	..	S														
20 (0.035)	..	..	..	..	..	..	..	..	..	..	X	X																						
19 (0.042)	..	..	..	..	..	X	X	X	X	X	X	X	X	X	X	..	..	S	..	S	..	S	..	S	..	S								
18 (0.049)	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X	X	..	..	..	..	..	..	..	..	..	..	S							
17 (0.058)	..	..	..	..	..	..	X	X	X	X	X	X	X	X	X	X	X	X	X	..	..	S	..	S	..	S	..	S	S					
16 (0.065)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X	X	X	..	..	..	..	..	S	..	..	S	S			
15 (0.072)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X	X	..	..	..	..	S	S	..	..	S	S	
14 (0.083)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X	X	X	..	..	..	S	..	..	..	S
13 (0.095)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	..	..	..	X	X	X	X	X	..	..	S	S	S	
12 (0.109)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X					
11 (0.120)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	X	X	X	X	X	X	X	X	X	S	..	S	..	S
Carbon Steel																																		
No. 24 (0.022)	X	X																																
22 (0.028)	X	X	X																															
20 (0.035)	X	X	X	X	..	X	X	X	X	X	X	X	X	X	..	..	..	S																
18 (0.049)	..	X	X	X	..	X	X	X	X	X	X	X	X	X	..	..	..	..	..	S	..	S	..	S	..	S								
17 (0.058)	..	..	X	X	..	X	X	X	X	X	X	X	X	X	X	X	X	X	..	..	..	..	..	..	..	..	S	S	S	S				
16 (0.065)	..	..	..	X	..	X	X	X	X	X	X	X	X	X	X	X	X	X	..	X	..	X	..	S	..	S	..	..	..	S	S	S	S	S
14 (0.083)	..	..	..	..	..	X	X	X	X	X	..	..	..	X	..	..	..	X	..	..	..	..	..	..	..	..	S	S	S					
13 (0.095)	..	..	..	..	..	..	..	..	..	X	X	X	X	X	..	X	..	X	..	X	..	..	..	S	..	..	..	..	..	S	S	S	S	S
11 (0.120)	..	..	..	..	..	..	..	..	..	..	..	..	..	X	..	X	..	X	..	..	..	X	..	..	..	S	..	S	..	S	..	S	..	S
Alloy Steel																																		
No. 24 (0.022)	X	X																																
22 (0.028)	X	X	X																															
20 (0.035)	X	X	X	X	..	X	X	X	X	X	X	X	X	X	..	..	..	S																
18 (0.049)	..	X	X	X	..	X	X	X	X	X	X	X	X	X	X	..	..	..	..	S	..	S	..	S	..	S								
17 (0.058)	..	..	X	X	..	X	X	X	X	X	X	X	X	X	X	X	X	X	..	..	..	..	..	..	..	..	S	S	S	S				
16 (0.065)	..	..	..	X	..	X	X	X	X	X	X	X	X	X	X	X	X	X	..	X	..	X	..	X	..	S	..	..	..	S	S	S	S	S
14 (0.083)	..	..	..	..	..	..	..	X	..	..	..	..	..	X	..	X	..	X	..	..	..	X	..	..	..	X	S	S	S					
13 (0.095)	..	..	..	..	..	..	..	..	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	..	..	S	S	S	S	S
11 (0.120)	..	..	..	..	..	..	..	..	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	X	..	S	..	S	..	S	..	S
3/16 (0.187)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	X	..	..	..	X										

X = round tubing; S = sizes used for streamline sections.

Table 48.—Round Tubing Characteristics

Outside diam., in.	Thickness B.W.G., in.	Section area, sq. in.	Weight per ft., lb.		Round		
			Steel	Aluminum alloy	Moment of inertia, I	Section modulus, Z	Radius of gyration, K
0.1875	24 (0.022)	0.01144	0.039	0.014	0.000040	0.000425	0.05903
0.1875	22 (0.028)	0.01403	0.048	0.017	0.000046	0.000491	0.05725
0.1875	20 (0.035)	0.01677	0.057	0.020	0.000051	0.000547	0.05532
0.2500	24 (0.022)	0.01576	0.054	0.019	0.000103	0.000827	0.08098
0.2500	22 (0.028)	0.01953	0.067	0.023	0.000122	0.000978	0.07911
0.2500	20 (0.035)	0.02364	0.081	0.028	0.000140	0.001122	0.07701
0.2500	18 (0.049)	0.03094	0.105	0.037	0.000165	0.001324	0.07314
0.3125	24 (0.022)	0.02008	0.068	0.024	0.000213	0.001363	0.10300
0.3125	22 (0.028)	0.02503	0.085	0.030	0.000256	0.001636	0.10107
0.3125	20 (0.035)	0.03051	0.104	0.037	0.000298	0.001910	0.09888
0.3125	18 (0.049)	0.04056	0.138	0.049	0.000364	0.002331	0.09475
0.3125	17 (0.058)	0.04637	0.158	0.056	0.000395	0.002527	0.09229
0.375	24 (0.022)	0.02440	0.083	0.029	0.000381	0.002035	0.12505
0.375	22 (0.028)	0.03052	0.104	0.037	0.000462	0.002463	0.12309
0.375	20 (0.035)	0.03739	0.127	0.045	0.000546	0.002912	0.12084
0.375	18 (0.049)	0.05018	0.171	0.060	0.000682	0.003636	0.11655
0.375	17 (0.058)	0.05776	0.197	0.069	0.000750	0.003999	0.11393
0.375	16 (0.065)	0.06330	0.216	0.076	0.000794	0.004234	0.11199
0.4375	24 (0.022)	0.02872	0.098	0.034	0.000621	0.002841	0.14710
0.4375	22 (0.028)	0.03602	0.123	0.043	0.000759	0.003470	0.14512
0.500	24 (0.022)	0.03304	0.112	0.040	0.00095	0.00378	0.16918
0.500	22 (0.028)	0.04152	0.142	0.050	0.00116	0.00464	0.16718
0.500	21 (0.032)	0.04705	0.160	0.056	0.00129	0.00518	0.16585
0.500	20 (0.035)	0.05113	0.174	0.061	0.00139	0.00556	0.16487
0.500	19 (0.042)	0.06043	0.206	0.073	0.00160	0.00639	0.16261
0.500	18 (0.049)	0.06943	0.236	0.082	0.00179	0.00714	0.16039
0.500	17 (0.058)	0.08054	0.275	0.097	0.00200	0.00800	0.15761
0.500	16 (0.065)	0.08883	0.303	0.107	0.00215	0.00859	0.15550
0.500	14 (0.083)	0.10873	0.371	0.131	0.00246	0.00983	0.15032
0.625	22 (0.028)	0.05252	0.179	0.063	0.00234	0.00750	0.21130
0.625	21 (0.032)	0.05962	0.203	0.072	0.00263	0.00841	0.20996
0.625	20 (0.035)	0.06487	0.221	0.078	0.00283	0.00906	0.20896
0.625	19 (0.042)	0.07693	0.262	0.092	0.00329	0.01051	0.20666
0.625	18 (0.049)	0.08867	0.302	0.106	0.00370	0.01185	0.20438
0.625	17 (0.058)	0.10331	0.352	0.124	0.00419	0.01342	0.20151
0.625	16 (0.065)	0.11435	0.390	0.137	0.00454	0.01454	0.19932
0.625	14 (0.083)	0.14133	0.482	0.170	0.00531	0.01700	0.19386
0.750	22 (0.028)	0.06351	0.217	0.076	0.00414	0.01105	0.25546
0.750	21 (0.032)	0.07218	0.246	0.087	0.00466	0.01243	0.25410
0.750	20 (0.035)	0.07862	0.268	0.094	0.00504	0.01343	0.25309
0.750	19 (0.042)	0.09342	0.318	0.112	0.00587	0.01566	0.25075
0.750	18 (0.049)	0.10791	0.368	0.129	0.00666	0.01776	0.24844
0.750	17 (0.058)	0.12609	0.430	0.151	0.00760	0.02027	0.24551
0.750	16 (0.065)	0.13988	0.477	0.168	0.00828	0.02208	0.24327
0.750	14 (0.083)	0.17392	0.593	0.209	0.00982	0.02619	0.23764
0.875	22 (0.028)	0.07451	0.254	0.089	0.00669	0.01529	0.29962
0.875	21 (0.032)	0.08475	0.289	0.102	0.00754	0.01723	0.29826
0.875	20 (0.035)	0.09263	0.315	0.111	0.00816	0.01865	0.29724
0.875	19 (0.042)	0.10990	0.375	0.132	0.00956	0.02184	0.29488
0.875	18 (0.049)	0.12715	0.433	0.153	0.01088	0.02487	0.29255
0.875	17 (0.058)	0.14887	0.507	0.179	0.01248	0.02853	0.28958
0.875	16 (0.065)	0.16541	0.564	0.198	0.01365	0.03121	0.28729
0.875	14 (0.083)	0.20652	0.704	0.248	0.01637	0.03742	0.28155
1.000	22 (0.028)	0.08550	0.291	0.103	0.01011	0.02021	0.34380
1.000	21 (0.032)	0.09731	0.332	0.117	0.01141	0.02282	0.34243

Table 48.—Round Tubing Characteristics (*Continued*)

Outside diam., in.	Thickness B.W.G., in.	Section area, sq. in.	Weight per ft., lb.		Round		
			Steel	Aluminum alloy	Moment of inertia, I	Section modulus, Z	Radius of gyration, K
1.000	20 (0.035)	0.10611	0.362	0.127	0.01237	0.02474	0.34140
1.000	19 (0.042)	0.12641	0.431	0.152	0.01453	0.02905	0.33903
1.000	18 (0.049)	0.14640	0.499	0.176	0.01659	0.03319	0.33667
1.000	17 (0.058)	0.17164	0.585	0.206	0.01911	0.03822	0.33368
1.000	16 (0.065)	0.19093	0.651	0.229	0.02097	0.04193	0.33137
1.000	14 (0.083)	0.23911	0.815	0.287	0.02534	0.05068	0.32553
1.000	13 (0.095)	0.27010	0.921	0.324	0.02796	0.05591	0.32172
1.000	11 (0.120)	0.33175	1.131	0.398	0.03271	0.06542	0.31398
1.125	21 (0.032)	0.10988	0.375	0.132	0.01642	0.02920	0.38659
1.125	20 (0.035)	0.11985	0.409	0.144	0.01782	0.03168	0.38557
1.125	19 (0.042)	0.14290	0.487	0.171	0.02098	0.03730	0.38319
1.125	18 (0.049)	0.16564	0.565	0.199	0.02402	0.04270	0.38082
1.125	17 (0.058)	0.19442	0.663	0.233	0.02775	0.04933	0.37780
1.125	16 (0.065)	0.21646	0.738	0.260	0.03052	0.05425	0.37547
1.125	14 (0.083)	0.27170	0.926	0.326	0.03711	0.06597	0.36957
1.125	13 (0.095)	0.30741	1.048	0.369	0.04111	0.07309	0.36571
1.250	21 (0.032)	0.12245	0.417	0.147	0.02272	0.03636	0.43078
1.250	20 (0.035)	0.13360	0.455	0.160	0.02467	0.03948	0.42975
1.250	19 (0.042)	0.15939	0.543	0.191	0.02911	0.04658	0.42735
1.250	18 (0.049)	0.18488	0.630	0.222	0.03339	0.05342	0.42497
1.250	17 (0.058)	0.21720	0.740	0.261	0.03867	0.06187	0.42194
1.250	16 (0.065)	0.24198	0.825	0.290	0.04260	0.06816	0.41959
1.250	14 (0.083)	0.30430	1.037	0.365	0.05207	0.08330	0.41364
1.250	13 (0.095)	0.34471	1.175	0.414	0.05787	0.09259	0.40974
1.250	11 (0.120)	0.42600	1.452	0.511	0.06876	0.11002	0.40176
1.375	20 (0.035)	0.14734	0.502	0.177	0.03309	0.04814	0.47392
1.375	19 (0.042)	0.17590	0.600	0.211	0.03910	0.05688	0.47152
1.375	18 (0.049)	0.20412	0.696	0.245	0.04492	0.06534	0.46913
1.375	17 (0.058)	0.23997	0.818	0.288	0.05213	0.07583	0.46608
1.375	16 (0.065)	0.26751	0.912	0.321	0.05753	0.08367	0.46372
1.375	14 (0.083)	0.33689	1.149	0.404	0.07059	0.10267	0.45774
1.375	13 (0.095)	0.38202	1.302	0.458	0.07867	0.11443	0.45379
1.500	20 (0.035)	0.16109	0.549	0.193	0.04324	0.05765	0.51810
1.500	19 (0.042)	0.19238	0.656	0.231	0.05116	0.06822	0.51569
1.500	18 (0.049)	0.22336	0.761	0.268	0.05885	0.07847	0.51330
1.500	17 (0.058)	0.26275	0.896	0.315	0.06840	0.09121	0.51024
1.500	16 (0.065)	0.29303	0.999	0.352	0.07558	0.10078	0.50787
1.500	14 (0.083)	0.36949	1.260	0.443	0.09305	0.12407	0.50184
1.500	13 (0.095)	0.41933	1.430	0.503	0.10394	0.13859	0.49788
1.500	11 (0.120)	0.52025	1.774	0.624	0.12478	0.16638	0.48974
1.625	19 (0.042)	0.20887	0.712	0.251	0.06547	0.08058	0.55987
1.625	18 (0.049)	0.24261	0.827	0.291	0.07540	0.09279	0.55747
1.625	17 (0.058)	0.28553	0.973	0.343	0.08776	0.10801	0.55440
1.625	16 (0.065)	0.31856	1.086	0.382	0.09707	0.11948	0.55202
1.750	18 (0.049)	0.26185	0.893	0.314	0.09478	0.10832	0.60164
1.750	17 (0.058)	0.30830	1.051	0.370	0.11046	0.12624	0.59856
1.750	16 (0.065)	0.34408	1.173	0.413	0.12230	0.13977	0.59618
1.750	14 (0.083)	0.43467	1.482	0.522	0.15136	0.17299	0.59010
1.750	13 (0.095)	0.49394	1.684	0.593	0.16967	0.19391	0.58609
1.750	11 (0.120)	0.61450	2.095	0.737	0.20519	0.23450	0.57785
1.875	17 (0.058)	0.33108	1.129	0.397	0.13677	0.14589	0.64273
1.875	16 (0.065)	0.36961	1.260	0.444	0.15155	0.16166	0.64034

Table 49.—Round and Streamline Tubing Characteristics

Outside diam., in.	Thickness, B.W.G., in.	Section area, sq. in.	Weight per foot, pounds		Round			Streamline ratio 2½:1		
			Steel	Aluminum alloy	Moment of inertia, *I*	Section modulus, *Z*	Radius of gyration, *K*	Moment of inertia, *I*	Section modulus, *Z*	Radius of gyration, *K*
2.000	21 (0.032)	0.19785	0.675	0.237	0.09581	0.09581	0.69589	0.03449	0.06036	0.41753
2.000	20 (0.035)	0.21606	0.737	0.259	0.10432	0.10432	0.69484	0.03756	0.06722	0.41690
2.000	19 (0.042)	0.25835	0.881	0.310	0.12386	0.12386	0.69242	0.04459	0.07803	0.41545
2.000	17 (0.058)	0.35386	1.206	0.425	0.16696	0.16696	0.68691	0.06011	0.10518	0.41215
2.000	16 (0.065)	0.39513	1.347	0.474	0.18514	0.18514	0.68451	0.06665	0.11664	0.41071
2.000	14 (0.083)	0.49986	1.704	0.560	0.23005	0.23005	0.67840	0.08282	0.14493	0.40704
2.000	13 (0.095)	0.56885	1.938	0.682	0.25855	0.25855	0.67436	0.09308	0.16287	0.40462
2.000	11 (0.120)	0.70874	2.416	0.850	0.31439	0.31439	0.66603	0.11318	0.19807	0.39962
2.125 (2⅛)	17 (0.058)	0.37663	1.284	0.452	0.20130	0.18946	0.73108			
2.125	16 (0.065)	0.42066	1.434	0.505	0.22336	0.21022	0.72868			
2.250 (2¼)	21 (0.032)	0.22298	0.760	0.268	0.13715	0.12191	0.78426	0.04937	0.07680	0.47056
2.250	19 (0.042)	0.29134	0.993	0.350	0.17761	0.15787	0.78079	0.06394	0.99458	0.46847
2.250	18 (0.049)	0.33882	1.155	0.407	0.20527	0.18246	0.77836	0.07390	0.11495	0.46702
2.250	16 (0.065)	0.44619	1.521	0.535	0.26651	0.23690	0.77286	0.09594	0.14925	0.46372
2.250	15 (0.072)	0.49265	1.680	0.591	0.29245	0.25994	0.77045	0.10528	0.16376	0.46227
2.250	13 (0.095)	0.64317	2.193	0.772	0.37408	0.33252	0.76265	0.13467	0.20948	0.45759
2.250	11 (0.120)	0.80300	2.738	0.964	0.45682	0.40607	0.75426	0.16446	0.25582	0.45256
2.250	3/16 (0.1875)	1.21462	4.142	1.458	0.65136	0.57898	0.73222	0.23449	0.36476	0.43933
2.375 (2⅜)	16 (0.065)	0.47171	1.608	0.566	0.31489	0.26517	0.81703			
2.375	15 (0.072)	0.52092	1.776	0.625	0.34570	0.29112	0.81463			
2.375	11 (0.120)	0.85011	2.898	1.020	0.54189	0.45633	0.79839			
2.500 (2½)	19 (0.042)	0.32433	1.106	0.389	0.24501	0.19601	0.86916	0.08820	0.12349	0.52150
2.500	18 (0.049)	0.37730	1.286	0.453	0.28344	0.22675	0.86673	0.10204	0.14285	0.52004
2.500	17 (0.058)	0.44496	1.517	0.534	0.33187	0.26550	0.86362	0.11947	0.16727	0.51817
2.500	16 (0.065)	0.49724	1.695	0.597	0.36876	0.29503	0.86121	0.13276	0.18587	0.51673
2.500	15 (0.072)	0.54920	1.872	0.659	0.40506	0.32405	0.85881	0.14582	0.20415	0.51528
2.500	14 (0.083)	0.63024	2.149	0.756	0.46077	0.36861	0.85504	0.16588	0.23222	0.51302
2.500	13 (0.095)	0.71778	2.447	0.861	0.51976	0.41581	0.85096	0.18711	0.26196	0.51058
2.500	11 (0.120)	0.89724	3.059	1.077	0.63691	0.50953	0.84252	0.22929	0.32100	0.50551
2.625 (2⅝)	15 (0.072)	0.57748	1.969	0.692	0.47085	0.35875	0.90298			
2.625	14 (0.083)	0.66283	2.260	0.795	0.53596	0.40835	0.89921			
2.625	11 (0.120)	0.94436	3.219	1.133	0.74244	0.56567	0.88967			
2.750 (2¾)	19 (0.042)	0.35732	1.218	0.429	0.32761	0.23826	0.95754	0.11794	0.15010	0.57452
2.750	18 (0.049)	0.41579	1.417	0.499	0.37928	0.27585	0.95511	0.13655	0.17379	0.57307
2.750	17 (0.058)	0.49052	1.672	0.589	0.44454	0.32331	0.95199	0.16003	0.20368	0.57119
2.750	16 (0.065)	0.54829	1.869	0.658	0.49438	0.35954	0.94958	0.17798	0.22651	0.56975
2.750	14 (0.083)	0.69543	2.371	0.835	0.61891	0.45012	0.94338	0.22280	0.28358	0.56603
2.750	13 (0.095)	0.79239	2.701	0.951	0.69909	0.50843	0.93928	0.25168	0.32031	0.56357
2.750	11 (0.120)	0.99149	3.380	1.189	0.85904	0.62476	0.93081	0.30925	0.39360	0.55849
2.750	3/16 (0.1875)	1.50944	5.146	1.811	1.24558	0.90588	0.90840	0.44841	0.57070	0.54504
2.875 (2⅞)	14 (0.083)	0.72802	2.482	0.874	0.71002	0.49393	0.98755			
2.875	13 (0.095)	0.82970	2.828	0.996	0.80246	0.55824	0.98345			
2.875	11 (0.120)	1.03861	3.541	1.246	0.98725	0.68679	0.97497			
3.000	19 (0.042)	0.39030	1.331	0.468	0.42696	0.28464	1.04592	0.15371	0.17932	0.62755
3.000	18 (0.049)	0.45427	1.549	0.545	0.49463	0.32976	1.04348	0.17806	0.20775	0.62609
3.000	17 (0.058)	0.53607	1.828	0.643	0.58021	0.38681	1.04036	0.20887	0.24369	0.62422
3.000	16 (0.065)	0.59934	2.043	0.719	0.64567	0.43045	1.03793	0.23244	0.27118	0.62276
3.000	14 (0.083)	0.76062	2.593	0.913	0.80965	0.53977	1.03174	0.29147	0.34005	0.61904
3.000	13 (0.095)	0.86700	2.956	1.040	0.91556	0.61028	1.02762	0.32960	0.38444	0.61657
3.000	11 (0.120)	1.08574	3.702	1.303	1.12765	0.75176	1.01911	0.40595	0.47361	0.61147
3.250 (3¼)	18 (0.049)	0.49276	1.680	0.591	0.63127	0.38847	1.13216	0.22726	0.24474	0.67929
3.250	17 (0.058)	0.58163	1.983	0.698	0.74100	0.45600	1.12873	0.26676	0.28728	0.67724
3.250	16 (0.065)	0.65039	2.127	0.781	0.82506	0.50773	1.12633	0.29702	0.31987	0.67568

Table 49.—Round and Streamline Tubing Characteristics (*Continued*)

Outside diam., in.	Thickness, B.W.G., in.	Section area, sq. in.	Weight per foot, pounds		Round			Streamline ratio 2½ : 1		
			Steel	Aluminum alloy	Moment of inertia, I	Section modulus, Z	Radius of gyration, K	Moment of inertia, I	Section modulus, Z	Radius of gyration, K
3.250	14 (0.083)	0.82581	2.815	0.991	1.03605	0.63757	1.12009	0.37298	0.40167	0.67205
3.250	13 (0.095)	0.94162	3.210	1.129	1.17267	0.72164	1.11598	0.42216	0.45463	0.66959
3.250	12 (0.109)	1.07559	3.667	1.291	1.32805	0.81726	1.11118	0.47809	0.51487	0.66671
3.250	11 (0.120)	1.17999	4.023	1.416	1.44715	0.89061	1.10743	0.52097	0.56108	0.66446
3.500 (3½)	17 (0.058)	0.62718	2.138	0.753	0.92906	0.53089	1.21710	0.33446	0.33446	0.73026
3.500	15 (0.072)	0.77540	2.643	0.931	1.13948	0.65113	1.21225	0.41021	0.41021	0.72735
3.500	14 (0.083)	0.89099	3.038	1.069	1.30116	0.74352	1.20948	0.46842	0.46842	0.72569
3.500	13 (0.095)	1.01623	3.465	1.219	1.47392	0.84224	1.20432	0.53061	0.53061	0.72259
3.500	12 (0.109)	1.16119	3.959	1.393	1.67078	0.95473	1.19951	0.60148	0.60148	0.71971
3.500	11 (0.120)	1.27423	4.344	1.529	1.82196	1.04112	1.19576	0.65591	0.65591	0.71746
3.750 (3¾)	17 (0.058)	0.67273	2.293	0.807	1.14652	0.61148	1.30548	0.41275	0.38523	0.78329
3.750	15 (0.072)	0.83195	2.836	0.998	1.40733	0.75057	1.30062	0.50664	0.47286	0.78037
3.750	14 (0.083)	0.95618	3.260	1.147	1.60803	0.85762	1.29681	0.57889	0.54030	0.77809
3.750	12 (0.109)	1.24680	4.251	1.496	2.06794	1.10290	1.28786	0.74446	0.69483	0.77272
3.750	11 (0.120)	1.36848	4.665	1.642	2.25651	1.20347	1.28410	0.81234	0.75819	0.77046
4.000	17 (0.058)	0.71828	2.449	0.862	1.39551	0.69775	1.39386	0.50238	0.43958	0.83632
4.000	16 (0.065)	0.80354	2.739	0.964	1.55570	0.77785	1.39142	0.56005	0.49005	0.83485
4.000	14 (0.083)	1.02137	3.482	1.226	1.95972	0.97986	1.38518	0.70550	0.61731	0.83111
4.000	13 (0.095)	1.16546	3.973	1.399	2.22282	1.11141	1.38103	0.80022	0.70019	0.82862
4.000	11 (0.120)	1.46273	4.987	1.755	2.75520	1.37760	1.37244	0.99187	0.86789	0.82346
4.250 (4¼)	16 (0.065)	0.85460	2.914	1.026	1.87139	0.88066	1.47980	0.67370	0.55482	0.88788
4.250	13 (0.095)	1.24007	4.228	1.488	2.67747	1.25999	1.46940	0.96389	0.79379	0.88164
4.500 (4½)	16 (0.065)	0.90564	3.088	1.087	2.22714	0.98984	1.56818	0.80177	0.62360	0.94091
4.500	15 (0.072)	1.00159	3.415	1.202	2.45545	1.09131	1.56574	0.88396	0.68753	0.93944
4.500	13 (0.095)	1.31468	4.482	1.578	3.19025	1.41789	1.55776	1.14849	0.89327	0.93466
4.500	11 (0.120)	1.65122	5.629	1.981	3.96269	1.76120	1.54914	1.42657	1.10956	0.92948
4.750 (4¾)	16 (0.065)	0.95670	3.262	1.148	2.62535	1.10541	1.65656	0.94513	0.69641	0.99394
4.750	15 (0.072)	1.05814	3.607	1.270	2.89519	1.21903	1.65412	1.04227	0.76799	0.99247
4.750	13 (0.095)	1.38930	4.736	1.667	3.76465	1.58512	1.64613	1.35527	0.99863	0.98768
5.000	16 (0.065)	1.00775	3.436	1.209	3.06839	1.22736	1.74494	1.10462	0.77324	1.04696
5.000	14 (0.083)	1.28212	4.371	1.539	3.87582	1.55033	1.73867	1.39530	0.97671	1.04320
5.000	13 (0.095)	1.46391	4.991	1.757	4.40417	1.76167	1.73450	1.58550	1.10985	1.04070
5.000	11 (0.120)	1.83972	6.272	2.208	5.47979	2.10192	1.72586	1.97272	1.38091	1.03552

AIRCRAFT MECHANIC'S CERTIFICATES

The importance of maintenance mechanics in airplane service is indicated by the regulations of the Civil Aeronautics Authority. Under former regulations, a temporary mechanic's or parachute rigger's certificate was issued in the field and expired in 60 days. Under the revision, a temporary certificate can be issued in the field, and unless notice of objection is given within 60 days, it becomes permanent. It must, however, be presented for endorsement every 2 years with a record of the mechanic's service under his certificate. If he fails to get an endorsement at the end of 2 years, or after reexamination, the certificate expires.

An applicant for a mechanic's certificate must be at least eighteen years old, of good moral character, and be able to read, write, speak, and understand the English language. United States citizenship was not necessary in the rulings of 1940, but this may of course be changed later.

There are three ratings: Aircraft Mechanic; Aircraft Engine Mechanic; and Parachute Rigger. To be eligible for an Aircraft Mechanic's rating the applicant must have both a theoretical and a practical knowledge of aircraft structure and rigging. This must include the control systems and aircraft appliances. He must be able properly to inspect, maintain, and repair aircraft, and he must be generally familiar with the provisions dealing with the airworthiness of aircraft equipment of all kinds and the methods of identifying aircraft of different types and classes. He must have had at least one year of practical aeronautical experience, or its equivalent, in the construction, inspection, maintenance, or repair of aircraft and their appliances. He must demonstrate his skill by written, oral, and practical tests.

To secure the rating of Aircraft Engine Mechanic, the applicant must have both theoretical and practical knowledge of aircraft power plants and propellers of all types, and must know how to inspect, maintain, and repair them. He must also have a general knowledge of the field covered by the Aircraft Mechanic's rating. He must be able to show his knowledge by written, oral, and practical tests.

The Parachute Rigger need not have a general knowledge of planes or engines, but he must know parachutes from A to Z. He must have packed at least 20 of them under the direct supervision of a certified parachute rigger, or a certified mechanic with a Parachute Rigger rating.

A mechanics certificate shall be of 60 days duration and unless the holder thereof is otherwise notified by the authority within such a period, shall continue in effect indefinitely. Forms for these applications can be obtained in any inspection district.

A method of packing parachutes is shown on pages 677–683.

As an indication of the importance of reliability on the part of the aircraft mechanics, the C.A.A. includes in its regulations such clauses as the following:

Only structural engine parts which are approved by the Secretary may be used to modify, maintain, or repair certificated engines. . . .

Mechanics' licenses will be suspended or revoked for violations of any provision of the Air Commerce Act or of any of the rules or regulations duly issued thereunder.

Doing any act in connection with aircraft or aircraft engines which is contrary to public safety.

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